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AUTHOR(S)- D. G. Estberg

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ABSTRACT

All results previously available indicate that there is a significant probability of the CM (Command Module) landing on land if an LEV (Launch Escape Vehicle) abort during the early part of Saturn V flight is necessary. Among the factors to which the CM landing point is sensitive, the most important are the winds and the initial conditions of the LEV caused by the abort situation.

In the previous studies the following worst case assumptions were made: abort initiated with uprange attitude and attitude rate errors, 95th percentile headwinds applied to the LEV trajectory from abort to parachute deployment, and 3σ launch escape motor thrust misalignment. The resulting land landing probability was 83% for pad abort from Launch Complex 39 using annual winds. The approach of this memorandum is to consider the effects of these factors statistically rather than in a worst case manner. Using this method, the above land landing probability is estimated to be 28%. Part of the difference between this and the previous result is due to the use of up-to-date LEV data from Apollo 8 simulations.

Improvement of this probability by variation of selected parameters is considered. The probability is improved by lower altitude of main chute deployment, longer LEV range, lower CM weight, and lower launch azimuth; also land landing probabilities are better for certain months and times of day. One suggested method of reducing the land landing probability is to increase the LEV range by realignment of the launch escape motor thrust vector so the LEV trajectory projection is perpendicular to the shoreline. This could reduce the above land landing probability to as low as 6%.

A near-pad abort is considered most probable in the 15 second period following launch. The values given above are representative of the land landing probabilities for aborts occurring during the first 10 seconds from launch; probabilities for other times of abort are given in the memorandum.

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SUBJECT: The Probability of Land Landing After an LEV Abort - Case 310

DATE: December 31, 1968

FROM: D. G. Estberg

TM-68-2013-6

TECHNICAL MEMORANDUM

I. INTRODUCTION

If it is necessary to abort while a manned Apollo spacecraft is on the launch pad or during the first 50 seconds of launch vehicle (LV) flight (a near-pad abort), there is a chance the Launch Escape Vehicle (LEV) will not carry the Command Module (CM) far enough downrange so that the CM will land in water. This problem does not exist for high altitude LEV aborts because after 50 seconds the LV has enough downrange velocity to assure a low probability of land landing. The purpose of this memorandum is to:

1. Survey the available information on land landing probabilities after an LEV abort,

2. Derive more realistic probabilities by use of statistical methods,

3. Suggest ways to reduce the land landing probability.

The land impact program to determine and improve the CM land landing capability is not considered in this memorandum.

Although results for Saturn V launches are desired much of the information available relates to the Saturn IB LV and is used as appropriate. The main difference between Saturn V and Saturn IB launches affecting land landing probabilities is that the Saturn V is launched from Pad 39* instead of Pad 34; since Pad 39 is farther from the shoreline, the probability of land landing is higher.

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*Pad 39 will be used to refer to either Pad 39A or Pad 39B; Pad 39B is not significantly farther from the shoreline than Pad 39A.

Following a section giving the summary and conclusions of this memorandum, a background section (Section III) gives a general description of LEV aborts and trajectories. Section IV discusses the main factors other than winds that affect the LEV trajectory and CM landing point: the initial conditions of the LEV caused by the abort situation, launch escape motor thrust alignment, and altitude of main chute deployment. The most important factor in determining the CM landing point is winds, and in Section V methods and results of application of wind profiles to trajectory simulations are given. In the first part of Section VI these results are used to explain the worst case land landing probability which has been given in previous studies. The rest of this section is concerned with a refined method to obtain a more realistic estimate of the probability of land landing. In Section VII the reduction in the land landing probability by variation of selected parameters is considered.

II. SUMMARY AND CONCLUSIONS

In previous studies to find land landing probabilities after an LEV abort occurring before about 20 seconds from Saturn V liftoff, the CM landing point with no winds applied during parachute descent was assumed to be about 1,200 feet inland from the nominal CM landing point. This assumption allowed for the worst case situation of abort initiated at uprange LV attitude and attitude rate errors plus 95th percentile headwinds applied to the LEV trajectory from abort to parachute deployment plus 3σ launch escape motor thrust misalignment. In addition, old LEV parameters were used placing the nominal CM landing point near the 10 foot depth line (the water must be at least 10 feet deep for a safe landing); for current Apollo 8 parameters the nominal CM landing point for abort before 20 seconds from launch is about 900 feet offshore from the 10 foot depth line. Statistical results for the studies above were derived by applying wind profiles to parachute descent, and the results are shown in Figure 12; land landing probabilities given for Saturn V are 83% and 58% for pad abort and 20 second abort, respectively.

In this memorandum Apollo 8 LEV parameters are used, and instead of making the summed worst case assumption, these factors (condition of the LV at the time of abort, winds applied to the LEV from abort to parachute deployment, and launch escape motor thrust misalignment) are treated statistically. Combining these factors and winds applied to parachute descent results in the land landing probabilities given in Figure 14, the values given above for pad abort and 20 second abort are more realistically estimated to be 28% and 34%, respectively.

Improvement of the land landing probability by variation of selected parameters is considered. It is improved by a lower altitude of main chute deployment, longer LEV range, lower CM weight and lower launch azimuth; also land landing probabilities are better for certain months and times of day. One possible method of increasing the LEV range would be to align the launch escape motor thrust vector so that the LEV trajectory is perpendicular to the 10 foot depth line, which results in an improvement of the land landing probability as shown in Figure 19. This method reduces the above values to as little as 6% and 27%, respectively. The probabilities given for pad abort are representative of the values for aborts occurring before 10 seconds from launch. Reduction of this probability is most important because near-pad abort is considered to be most probable before 15 seconds from launch. Another method of increasing LEV range which is only effective for aborts after 10 seconds would be the S-tilt method (changing the commanded pitch program so the LV gains range faster). The improvement in the land landing probability resulting from the combination of this method and thrust realignment is also shown in Figure 19; this method reduces the 27% probability for 20 second abort to 19%. In addition this figure shows the combined effect of "sky diving" (deploying the main parachute at the lowest possible altitude) and thrust realignment; the 27% for 20 second abort would be reduced to 12% by this method and again the 6% probability for pad abort is unchanged.

III. BACKGROUND

General Description of LEV Aborts In case of abort during the first stage of LV flight, the LEV (Figure 1) along with the Earth Landing Subsystem (ELS), is provided for astronaut escape. A near-pad abort is most likely to occur before 15 seconds from liftoff because during this period there is the highest probability of LV malfunction, launch transients occur, pitch and roll commands are initiated and tower clearance (along with its associated yaw command) is completed [5, 6 and 7]*. Figure 2 illustrates schematically the sequence of events that occurs after a near-pad abort. A detailed description of this sequence is given in Appendix A, but briefly the events occurring after abort are as follows. The launch escape motor is used to accelerate the LEV away from the LV, while the pitch control motor fires briefly to pitch the vehicle downrange.

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*Brackets, [], enclose reference numbers.

After the thrusting phase the canards are deployed to pitch the vehicle 180°. After blunt end capture, the launch escape tower and the boost protective cover (which protects the CM from heat during LV boost and from exhaust damage by the launch escape and tower jettison motors) are jettisoned using the tower jettison motor. The apex cover (forward heat shield) is then jettisoned using thrusters and a drag parachute to uncover the ELS parachutes. The mortars are fired to deploy the two drogue parachutes in the reefed configuration, and they are disreefed after loads reduce sufficiently. When the drogue chutes are released, the mortars for the three pilot chutes are fired. The pilot chutes deploy the three main chutes which are disreefed in two stages.

Relation of Pad and Safe Landing Area A safe water landing requires the water to be at least 10 feet deep.* At its closest point the 10 foot depth line, which can be assumed to be straight, is about 1900 feet from Pad 34 in a direction of 70 degrees azimuth (measured clockwise from north) and 3100 feet from Pad 39 in a direction of 52 degrees azimuth.

In considering the relation of the CM landing point and the 10 foot depth line it is only necessary to consider the distance measured perpendicular to the 10 foot depth line, referred to as the onshore-offshore distance. A positive direction will be taken to be offshore (generally east).

Typical LEV Trajectories Typical LEV trajectories for a pad abort and for an abort occurring 42 seconds after launch are shown in Figure 3; the apogee altitude and the range are shown for aborts occurring at other times. The 20 second abort trajectory has a shorter range than aborts at previous times because the pitch control motor becomes less effective as aerodynamic effects become stronger. For aborts after 20 seconds the LV downrange velocity and range begin to have more effect on LEV range.

Using LEV range and azimuth data the onshore-offshore distance of the CM landing point from the 10 foot depth line can be determined. The following data from References 7 and 9 assume no winds, nominal LV attitude and attitude rate at the time of abort and a nominal LEV:

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*To be conservative the 10 foot depth line at low tide is considered, although it does not change much with tide. In some abort landing point prediction maps the 18 foot depth line is also drawn in; this is a necessary consideration if only two of the three main parachutes deploy.

TABLE I

Time of Abort (seconds)	Onshore-Offshore Distance (feet)	
	Saturn IB (Apollo 7)	Saturn V (Apollo 8)
0	2650	950
10	2200	800
20	2350	890
30	3200	2280
40	5100	4780
50	8700	8790

IV. LEV TRAJECTORY SENSITIVE PARAMETERS

Introduction The data in the last subsection were determined for a specific set of LEV parameters. This section discusses three factors to which the land landing probability is very sensitive: LV conditions at the time of abort, launch escape motor thrust alignment and altitude of main chute deployment.

LV Conditions at the Time of Abort In general when a LV malfunction occurs the state vector (position, attitude and their derivatives) of the vehicle begins to change from its nominal value. Abort is initiated when the malfunction is detected by means of the Emergency Detection System (EDS) [10], and the state vector of the LV at that time determines the initial conditions of the LEV. In LEV trajectory simulations the position and velocity of the LV are assumed nominal at the time of abort, although they may have a significant effect on the LEV trajectory [1]. One means of detection of a LV malfunction is by determining when the attitude or attitude rate reach certain limits; therefore, for the malfunctions that use this means of detection we know something about the attitude or attitude rate at the time of abort [12, 13 and 15]. The values that are used in LEV trajectory simulations when abort is assumed to be due to a LV malfunction are called "tipover" attitudes and attitude rates. Before May, 1968, the tipover attitudes and attitude rates were ± 5 degrees and ± 3 degrees/second on the pitch or yaw [16 and 17]; much of the land landing probability results available use these old tipover attitudes and attitude rates. Currently, the values used are ±3 degrees and ±5 degrees/second for Saturn IB and ±3 1/2 degrees and ±4 degrees/second for Saturn V [8]. These current values were determined by using the attitude rate limits and assuming the specific LV malfunction all engines hardover. Roll and roll rate have been assumed to be nominal in essentially all LEV trajectory simulation [1 and 19].

The effect that initiating abort at the Saturn IB tipover attitudes and attitude rates has on the CM range is shown in the table in Figure 4. This table also shows the effect of 3σ launch escape motor thrust misalignment, which is about .3 degree. The combination of these two effects is called tipover: for example, uprange tipover is caused by aborting with uprange tipover attitude and attitude rate (a negative* pitch and pitch rate) with a 3σ thrust misalignment in the uprange direction. Pad abort** trajectories for uprange and downrange tipover are shown in Figure 4 for Saturn IB; this figure shows that uprange tipover shortens LEV range by almost 50% compared to a nominal trajectory, and downrange tipover increases range by about 33%. In later sections it will be assumed that the data given in Figure 4 is also applicable to the Saturn V.

Launch Escape Motor Thrust Alignment Thrust alignment of the launch escape motor is determined by ΔZ which is defined in Figure 1; note thrust alignment, which can be adjusted, is distinct from thrust misalignment, which is random. ΔZ is always set as low as possible so that the CM achieves maximum range and is as far away as possible from the pad residual fire area and from the fireball of a potential LV explosion. The lower limit of ΔZ is determined by the maximum main chute load which occurs for downrange tipover (this is worst case because parachute loads are higher for lower altitude LEV trajectories). Also ΔZ must be such that, with downrange tipover and only two main chutes deployed, the altitude of main chute deployment is high enough (2500 feet) so that terminal velocity is reached in the descent, but in practice ΔZ is usually determined by parachute loads.

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*The CM pitch axis is pointed north when the vehicle is on the pad. This is the opposite of the LV sign convention.

**In land landing probability work, "pad abort" means abort immediately after liftoff so that it is possible for the LV to be at the tipover attitudes and attitude rates; "static pad abort" is used to describe aborts occurring before this is possible.

The effect of ΔZ adjustments on the LEV trajectories for various missions for pad abort is shown in Figure 5; the nominal LEV range has varied from 4,150 to 5,700 feet and is presently 5, 150 feet for Apollo 8. The reasons that have caused ΔZ to vary from mission to mission are:

1. Change in weight of the components of the LEV, particularly the CM (see the table in Figure 5),

2. Redesign of the parachutes, required because of the increase in CM weight,

3. Change of the tipover attitude and attitude rate,

4. Difference between Saturn IB and V tipover attitudes and attitude rates,

5. Difference between the altitude of the LEV when the Saturn IB or V is on the pad (178 feet),

6. Update of the aerodynamic drag data for the CM and the parachutes.

Altitude of Main Chute Deployment Main chute deployment is nominally automatically initiated at 28 seconds after abort or, if the LEV apogee is above 15,900 feet (i.e., if the abort occurs after about 38 seconds from launch), when the altitude falls to 10,500 feet. In addition the main parachutes can be deployed manually after drogue chute deployment (which occurs at 16 seconds after abort) if the altitude falls below an alidade marker on the altimeter. The alidade marker is set at about 3300 feet [1] instead of the 2500 feet minimum altitude for main chute deployment because of possible error in the altimeter reading [6]. This early manual main chute deployment is only required for aborts that have downrange tipover and that occur before about 10 seconds from launch.

For application in later sections, it is necessary to know the altitude of main chute deployment if deployment occurs 28 seconds after abort. This information for a nominal trajectory and trajectories with uprange and downrange tipover is given in Figure 6.

V. EFFECTS OF WINDS ON THE LEV TRAJECTORY

Application of Wind Data to Trajectory Simulations Observed wind data is available in many different forms, and care must be taken in its application to obtain meaningful results concerning the probability of land landing. A qualitative idea of the effect of winds can be obtained by application of a single wind profile to the LV and LEV trajectory, as shown in Figure 7. Wind has little effect on the LV until after about 35 seconds, wind has some effect on the LEV trajectory before main chute deployment and wind has the most effect on the main parachute descent. These results were obtained by applying the 95th percentile scalar winds for March (one of the windiest months of the year) in the uprange or downrange direction. Note that this is far worse than a 95th percentile situation because it is assumed that the 95th percentile scalar winds exist at all altitudes at the same time and blow in the same direction.

Statistical analysis is necessary to obtain quantitative results on the effect of winds on the LEV trajectory. Two methods which require additional statistical reduction of the wind data are described in Appendix B, but few results using these methods are available. The conceptually simplest and yet the most accurate approach is a Monte Carlo method with all data used; i.e., run an LEV trajectory simulation from drogue chute deployment to touchdown for each wind profile available and then statistically reduce the CM landing points to obtain a distribution function with the onshore-offshore distance as the random variable. This method was used by MSC to obtain the results presented in the next subsection. The main disadvantage of this method is that in general it is not practical to use an integrated LEV trajectory because of the computer time necessary; in particular, the LEV trajectory before parachute deployment was not included and a closed-form equation for parachute descent was used.*

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*The equation (which was derived at MSC [29]) gives only the horizontal component of the descent path:

$$x = Ce^{-Kt} + (I - S/K)t + (S/K)t^2 \quad .$$

It is assumed that the vertical component is the same as was given by a 12 degree-of-freedom computer program (6 degrees-of-freedom each for the parachute and the CM) used to simulate the parachute descent with no winds applied; the equation is applied to layers in which it can be assumed the wind velocity is linear as a function of the descent time (the constants I and S determine this straight line). The constant C is $(I-S/K-\dot{x}_o)/K$ where $\dot{x}_o$ is determined at the beginning of each layer from the derivative of the above equation. K is an aerodynamic constant for the parachutes and is derived empirically to get a close match between paths calculated by this equation and the 12 degree-of-freedom simulation.

Result of Application of Winds to the LEV Trajectory

The only available statistical results from application of wind profiles to parachute descent were presented in Reference 30. A Saturn V LV was used, and the CM weight used was 13,000 pounds (this is the weight at main chute deployment including RCS propellant). Abort was assumed to occur with uprange tipover. This study used eight years of wind data combined (described in Appendix C), so the results are annual rather than applicable to each month or time of day. The result of statistical reduction of this wind data is informative: representative mean and standard deviation profiles for onshore-offshore winds are shown in Figures 8 and 9. The mean wind is small compared to the standard deviation and blows onshore below 4,500 feet and offshore above that; the standard deviation increases sharply between 1,000 and 2,500 feet. If the vector wind data is broken into components it is found that each component is approximately normally distributed.

Figure 10 gives the distance between the mean landing point with winds and the landing point with no winds as a function of time of abort. The distance is measured perpendicular to the 10 foot depth line (onshore-offshore distance). Data was given in Reference 30 for only the end points of each curve: main chute deployment at 28 seconds after abort and at 2800 foot altitude (only the 2800 foot point was available for 40 second abort so this curve was estimated). The conclusions to be drawn are (1) for early near-pad aborts and low altitude main chute deployment the mean landing point with winds applied is not significantly different from the landing point with no winds, (2) as the altitude of main chute deployment is raised the mean landing point gradually moves out to sea and (3) for main chute deployment at a constant altitude the landing point moves out to sea for later times of abort because of the effect of wind on the drogue parachutes. These conclusions are what would be expected after looking at the mean annual onshore-offshore wind speed profile (Figure 8). Reference 30 also gives distribution functions showing where the CM is likely to land, because of winds applied to parachute descent, relative to the mean landing point for various times of abort. These distribution functions are approximately normal as will be shown in Appendix D. A plot of the estimated standard deviations of these distributions against altitude of main chute deployment is shown in Figure 11. It is important to notice that the standard deviation is large compared to the mean and that in the 4,000-5,000 foot main chute deployment region there is a rapid change in the standard deviation (i.e., CM landing points are much more concentrated for main chute deployment below about 4,000). Figures 10 and 11 are used in the next section to derive land landing probabilities.

The remainder of this section addresses the final wind-sensitive variable during LEV aborts: the CM position at drogue chute deployment. LEV trajectories from abort to drogue chute deployment were simulated by a 6 degree-of-freedom computer program [34 and 35]. When 95th percentile component headwinds were applied to a pad abort trajectory, the range at drogue chute deployment decreased about 500 feet [1 and 30]. This is worse than a 95th percentile situation because it was assumed that the 95th percentile winds exist at all altitudes at the same time (the correlation coefficient between surface and 1 kilometer altitude east-west annual winds is only 0.660 and between 1 and 2 kilometer winds is 0.851 [32]), so it will be assumed that this represents a 3σ situation (99.87 percentile). Since this is the only data point available we must assume that the standard deviation increases with the time of abort (and thus the altitude of the trajectory) in a manner similar to the increase of standard deviation with altitude of main chute deployment. The standard deviations that will be used in later section are as follows:

TABLE 2

Time of Abort (seconds)	Standard Deviation (σ)
pad	170 feet
10	200 "
20	250 "
30	350 "
40	400 "
50	450 "

It will further be assumed that the mean range with winds applied to the LEV trajectory from abort to parachute deployment is the same as the range with no winds applied.

VI. THE PROBABILITY OF LAND LANDING AFTER AN LEV ABORT

Prior Results on Land Landing Probability In simple terms MSC's results on land landing probability were obtained by running parachute descent trajectories through each wind profile available, counting the number of trajectories with the CM landing point on land and dividing this by the total number of trajectories. However, in order to introduce the more general methods used in the next subsection, we may incorporate the intermediate results of the above method, which were presented in Figures 10 and 11, into a statistical model that can be used to find this same probability, as shown by the following example. Consider a Saturn V launch with a 13,000 lb. CM (weight at main chute deployment including RCS propellant). Assume a pad abort that is initiated at the old uprange tipover attitude and attitude rate. First we must find the landing point with no winds applied during parachute descent. The LEV trajectory range with uprange tipover and no winds is 3,100 feet [30], but this is shortened to 2,600 feet because of 95th percentile headwinds applied to the trajectory from the abort to drogue chute deployment (3σ from Table 2). The azimuth of this trajectory is about 96° [8]*, and the azimuth of the line perpendicular to the ten foot depth line is 52°, so the angle between these directionsis 44°. Projecting the range on the line perpendicular to the ten foot depth line gives 1,870 feet. The pad is 3,100 feet from the 10 foot depth line, and hence the CM landing point without winds applied during parachute descent is on land and 1,230 feet from the 10 foot depth line. To apply wind statistics, first note from the upper point of the pad abort curve in Figure 10 that the mean landing point with winds applied is at the same point as the landing point with no winds, so the mean landing point is also 1,230 feet from the 10 foot depth line. From Figure 11 we see that the standard deviation of the distribution of landing points is 1,300 feet. Thus, 1,230 feet represents 0.95 standard deviation, and, referring to a table of the normal distribution function, this implies that 83% of the CM landing points would be expected to be on land (i.e., west of the 10 foot depth line).

MSC results have been published in several places for a variety of purposes. An example is given in Figure 12; the 83% probability obtained above for Saturn V pad abort is shown. One of the most accurate uses of MSC's probability results was to estimate the probability of launch for Apollo 7 assuming the countdown would be halted if the Real Time Auxiliary Computing Facility (RTACF) predicted land landing for an abort occurring before 15 seconds from launch; further information on the RTACF program and the probability of a hold because RTACF prediction of land landing can be found in References 20 and 37 through 44. Another use of MSC's results has been to give some indication of the actual probability of land landing. The following summarizes the assumptions that make these land landing probability results worst case:

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*This is indicated by the fact that the launch escape motor thrust vector is pointed in approximately this direction as shown in Figure 1.

1. Uprange tipover is assumed (recall this includes both abort at the uprange tipover attitude and attitude rate and 3σ thrust misalignment in the uprange direction).

2. Early manual main chute deployment is assumed to occur at 4,300 feet instead of at 3,300 feet in order to allow for worst case altimeter errors [26].

3. 95th percentile headwinds are applied to the LEV trajectory from abort to parachute deployment for pad abort through 10 second abort and no winds applied for aborts occurring after that (from Figure 8 it is seen that this is conservative in both cases).

4. A 13,000 pound CM was used whereas the current weight of CM-103 is 11,769 pounds [46]. The weight given is the weight at main chute deployment including RCS propellant.

As would be expected from Figure 4, the amount of uprange tipover has a large effect on the land landing probability. In Figure 13 is shown the results of a quantitative study [20] of this effect for pad abort of Apollo 7 with September winds. If abort is initiated with a nominal LV attitude and attitude rate, then the probability of land landing is only about 10%, but if abort is initiated at the current Saturn IB uprange tipover attitude and attitude rate, then the probability is 67%; if abort is initiated at the old uprange tipover attitude and attitude rate then the probability is 62%.

<u>Land Landing Probabilities Found by a Refined Method</u>
In order to find the actual probability of land landing after an LEV abort at a given time from launch, it would be necessary to know the relative probability of each possible LV malfunction that could cause abort at that time and to know the initial conditions of the LEV caused by the abort situation for each malfunction. Since this is impossible and conditions of the LEV at abort initiation are quite important in determining land landing probabilities (as shown in the last section), it is not possible to find true land landing probabilities. The method developed at MSC to find land landing probabilities assumed a worst case situation, but indicated that land landing was a problem. The purpose of this section is to obtain a more realistic estimate of the land landing probability. This can be done for two cases: abort initiated with nominal attitude and attitude rate and abort initiated with tipover attitudes and attitude rates.

The most important factors that cause dispersion in the CM landing point are:

1. Wind applied to parachute descent, which causes the CM landing point to be displaced from the landing point with no winds as given in Figures 10 and 11.

2. Wind applied to the LEV trajectory from abort to drogue chute deployment, which causes a distribution of the CM landing points with a standard deviation given in Table 2 on page 10.

3. Initiation of the abort at the tipover attitudes and attitude rates, which causes the CM landing point to be moved from nominal in the uprange, downrange, right or left direction as indicated in the table in Figure 4.

4. Thrust misalignment, which results in a 3σ deviation in the CM landing point as given in the table in Figure 4.

The first two effects are not independent; in fact, to be conservative it is assumed that they are perfectly correlated, so the distribution function of their combined effect has a standard deviation equal to the sum of their standard deviations. This combined effect is obviously independent of the other effects. For the case of abort initiated at the tipover attitudes and attitude rates, if it is assumed that the LEV initial conditions are equally likely to be in the uprange, downrange right or left direction, the effect of 1. and 2. can be graphically combined with the effect of 3.:

$$1/4\ F_u + 1/4\ F_d + 1/4\ F_r + 1/4\ F_l$$

where F_u, F_d, F_r and F_l are the distribution functions for the of winds with abort initiated at the tipover attitude and attitude rates in the uprange, downrange, right and left directions, respectively, centered at their respective mean landing points with winds applied. For simplicity this resulting distribution can be assumed normal and its standard deviation calculated. This value can be root-sum-squared with the standard deviation for the fourth factor to give the final standard deviation. For the case where abort is initiated with a nominal LV the procedure is similar, but only one distribution function for the effect of winds is needed so the graphical combination is not necessary. In Table 1 on page 5 are given the distances of the nominal CM landing point from the 10 foot depth line. Using these values the mean landing points (after applying winds and allowing for the nonsymmetry of the tipover landing points) can be found from Figure 10 or from the graphs made above for combining distribution functions. Finally, the mean landing distances from the 10 foot depth line can be put in units of the corresponding standard deviations found above, and the probability of land landing found from a normal distribution table. A numerical example of this procedure is given in Appendix D.

The resulting land landing probabilities for the two cases are shown in Figure 14. These probabilities are substantially less than those obtained by MSC's method given in Figure 12 (28% instead of 83% for pad abort and 34% instead of 58% for 20 second abort). Part of this difference is due to the method used, but also part is due to LEV parameter changes causing a difference LEV range as discussed in Section IV on page 7. For example, it can be easily shown that if Apollo 8 range data were used MSC's method of obtaining land landing probability would give about 57% for pad abort instead of 83%.

Figure 15 presents information that is helpful in explaining the shape of the land landing probability curves. In the top half of this figure is shown the approximate standard deviation resulting from combining the factors that cause dispersion in the CM landing point given on page 13; also shown is the distance of the CM landing point from the 10 foot depth line. We may conclude:

1. For early aborts the standard deviation is relatively small so the distance of the mean landing point from the 10 foot depth line is very important, which accounts for the difference in Saturn IB and Saturn V land landing probabilities.

2. The land landing probability is maximum at about a 25 second abort because until about 25 seconds the distance of the mean landing point from the 10 foot depth line stays about constant, but after 10 seconds the standard deviation increases sharply. Land landing probability drops off after 30 seconds because of a rapid increase in LEV range along with some help from the mean offshore wind.

Wind applied to parachute descent is by far the main contributor to dispersion of the CM landing point. The lower half of Figure 15 shows the importance of the other three factors relative to each other. We see for aborts before about 20 seconds from launch, dispersion due to winds applied to the LEV trajectory from abort to drogue chute deployment and dispersion due to abort initiated at the tipover attitudes and attitude rates are about equally important, and thrust misalignment is less important than these. For aborts after about 20 seconds only winds are important. This explains the fact that the land landing probability curves for abort initiated with tipover attitudes and attitude rates and with nominal attitude and attitude rate are only different for aborts before 20 seconds from launch.

The results of this subsection were derived from the available data and some data that had to be estimated. The following summarizes the assumptions that had to be made and some of the possible sources of inaccuracies.

1. The lack of sufficient data on the effect of winds on the LEV trajectory from abort to drogue chute deployment probably introduces the largest source of error in the results. As pointed out in the last paragraph, this effect is the second most important factor contributing to dispersion of CM landing points.

2. The range of the CM landing point, which is mainly determined by the launch escape motor thrust alignment, was taken from the latest operational abort plans for Saturn IB and Saturn V launches. It was assumed that thrust alignment has little effect on other data (such as standard deviation in landing points because of winds and altitude of 28 second main chute deployment); this other data was derived for different thrust alignments.

3. It was assumed that the CM landing point statistics (mean and standard deviation of landing points because of winds applied to parachute descent) are mainly determined by the altitude of main chute deployment. In turn the altitude of main chute deployment, for deployment 28 seconds after abort, had to be estimated for downrange tipover (Figure 6). Also these statistics were known for only two altitudes of main chute deployment so values in between had to be estimated (Figures 10 and 11). Besides altitude of main chute deployment, the CM landing point statistics are influenced by the LEV trajectory shape, in particular the altitude of drogue chute deployment; because the data used was for uprange tipover, the probability results are

conservative*. The CM landing point statistics were derived from the component of the wind data perpendicular to the 10 foot depth line for Pad 39, so it was assumed that the statistics would be about the same for the component perpendicular to the 10 foot depth line for Pad 34. Finally, it must be recalled that the results were based on annual winds, but decisions for specific flights should be based on results for each month of the year and time of the day; an indication of the variation of land landing probability with month and time of day is given in the next section.

4. The amount of displacement in the CM landing point from the nominal landing point caused by initiating abort at the current Saturn IB tipover attitudes and attitude rates (Figure 4) was taken from the latest Saturn IB (Apollo 7) operational abort plan. Corresponding data for the current Saturn V tipover attitudes and attitude rates is not given in the latest Saturn V (Apollo 8) operational abort plan, so Figure 4 was assumed applicable for the Saturn V. Indications are that the displacement is less for Saturn V, so the Saturn V probabilities given in this memorandum are conservative. However, recall that the current tipover attitudes and attitude rates are for a specific LV malfunction; other LV malfunctions could cause higher land landing probabilities.

5. In order to be able to combine distribution functions by adding or root-sum-squaring of standard deviations, it was assumed that the distributions were normal, which is seen to be only approximately true in Appendix D. This assumption could be avoided by using numerical integration to combine distribution functions, but it was not felt worth while until more accurate data is available.

VII. PARAMETRIC ANALYSIS OF LAND LANDING PROBABILITIES

Introduction In this section the sensitivity of the land landing probability to those parameters that are preset before the flight are considered, and possible methods of improving land landing probabilities are given. The subsection dealing with month of year and time of day uses land landing probabilities

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*Uprange tipover implies higher drogue chute deployment altitude than without tipover, which implies larger standard deviations, which implies higher land landing probabilities if the mean landing point with winds applied is in water.

derived by MSC (and therefore assumes worst case conditions), while the remaining subsections use the land landing probability found by the method developed in this memorandum.

Month of Year and Time of Day As shown in Figure 16 the variation of land landing probability with time of year is significant; land landing probabilities are lowest during the first part of the year and near the middle of the year. The variation with time of day is only important for May through September; then the land landing probability is lowest in the morning. The small variation of the probability with time of day for certain months was confirmed by another method (see Appendix B).

Altitude of Main Chute Deployment Using the method developed in the last section, the variation of land landing probability with altitude of main chute deployment (for various times of abort*) can be found and is shown in Figure 17. In general the land landing probability increases faster with main chute deployment altitudes between 4,000 and 5,500 feet than it does with other altitudes. Markings on the curves indicate the altitude of 28 seconds main chute deployment, so it can be seen that a worth-while improvement in land landing probabilities can be made for aborts after 10 seconds by deploying the main chute at 3,300 feet. This procedure, which is called "sky diving", was considered but rejected because this delayed main chute deployment would have to be done manually [45 and 47].

LEV Range The effect of increasing the LEV range perpendicular to the 10 foot depth line is appreciable, especially for aborts before 10 seconds, as shown in Figure 18 (derived from Figure A2 of Appendix D); for example, increasing the onshore-offshore distance 1000 feet could decrease the percent probability over 30%. Since probability of abort is considered highest in the 15 second period following liftoff this is the most appropriate method of improving land landing probability. The following are four possible methods of doing this.

1. Presently the launch escape motor thrust is aligned such that for pad abort the trajectory has an azimuth of about 96 degrees. For Pad 39 this is 44 degrees from being perpendicular to the 10 foot line, so much could be gained if the thrust alignment could be adjusted in the negative Y direction (see Figure 1) to make

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*Aborts after 30 seconds were not considered because in the current sequence of events main chute deployment is always at 10,500 feet for aborts after about 37 seconds and aborts at 40 and 50 seconds have a relatively low land landing probability as was seen in Figure 14.

the azimuth perpendicular to the shore. One difficulty is that the pitch control motor thrust is directed west, so if this direction could not be changed some pitching moment (and therefore range) would be lost; although this effect could be significant [48], ΔY could still be optimized to decrease land landing probability as much as possible. This possible difficulty was not considered in Figure 19, which shows that this method could cut the land landing probability more than half for aborts before 10 seconds.

2. The above method does not do too much to improve probabilities after 10 seconds, but this can be remedied if it is used in conjunction with the "sky dive" procedure (considered in the last subsection and resulting in the combined effect shown in Figure 19) or with the S-tilt method. This last method, which changes the commanded pitch program so the LV gains range sooner, was proposed in 1967 [33], but was discarded because it only helps the land landing probability after 10 seconds. As shown in Figure 19, the S-tilt method is worth considering in conjunction with ΔY thrust alignment; thrust realignment reduced the land landing probability for 20 second aborts down to 27%, and the S-tilt method could reduce this to 19%, while "sky diving" could reduce the 27% to 12%.

3. The range of the LEV could be increased by increasing the burning time of the launch escape motor. A study has been made with increased impulse of the launch escape motor [1 and 29] with the result that the speed at drogue chute deployment was increased so much that after the thrust was realigned to satisfy main chute load limits, no increase in the range was achieved. But it has not been shown that the thrust profile could not be adjusted so that this problem would not be encountered.

4. The study mentioned in 3. to increase launch escape motor impulse was part of work done by MSC to consider ways of increasing LEV capabilities for the Apollo Applications Program. The conclusion of this work was that the only way to improve LEV capabilities was to have a "Steerable Abort System" (onboard guidance and navigation system) to guide the LEV to a water landing [1 and 49].

<u>CM Weight</u> As mentioned previously a change in CM weight causes a change in launch escape motor thrust alignment which along with the weight change causes a change in LEV range. Although more information is needed to draw a definite conclusion, indications are that land landing probability increases appreciably with CM weight.

Launch Azimuth So far in this memorandum only a 72° launch azimuth has been considered; the effect of other launch azimuths on land landing probabilities for Saturn V is shown in Figure 20. This was obtained by using the statistical method of this memorandum to find land landing probabilities with the appropriate roll command applied. The result shows that for a 90° launch azimuth the probability is not significantly higher, but for a 108° launch azimuth the percent probability is up to 20% higher. Note that the variation of land landing probability with launch azimuth would be greatly reduced if ΔY thrust alignment were used to increase LEV range.

D. G. Estberg

D. G. Estberg

2013-DGE-bjw

Attachments:
  Figures 1-20
  Appendices
  Table
  Figures A1-A4
  References

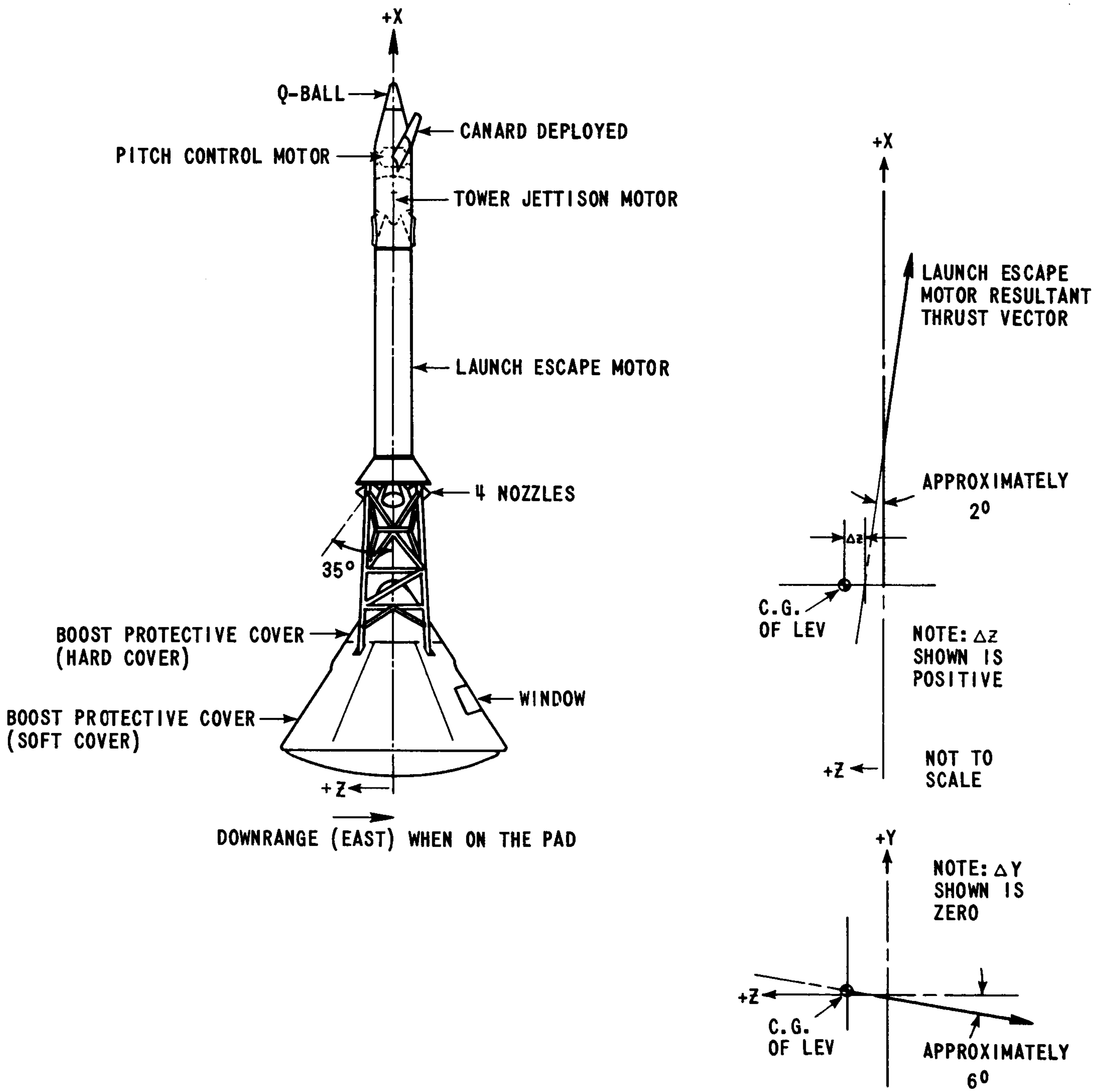


FIGURE 1 - LAUNCH ESCAPE VEHICLE CONFIGURATION
(REFERENCES 1, 3 AND 4)

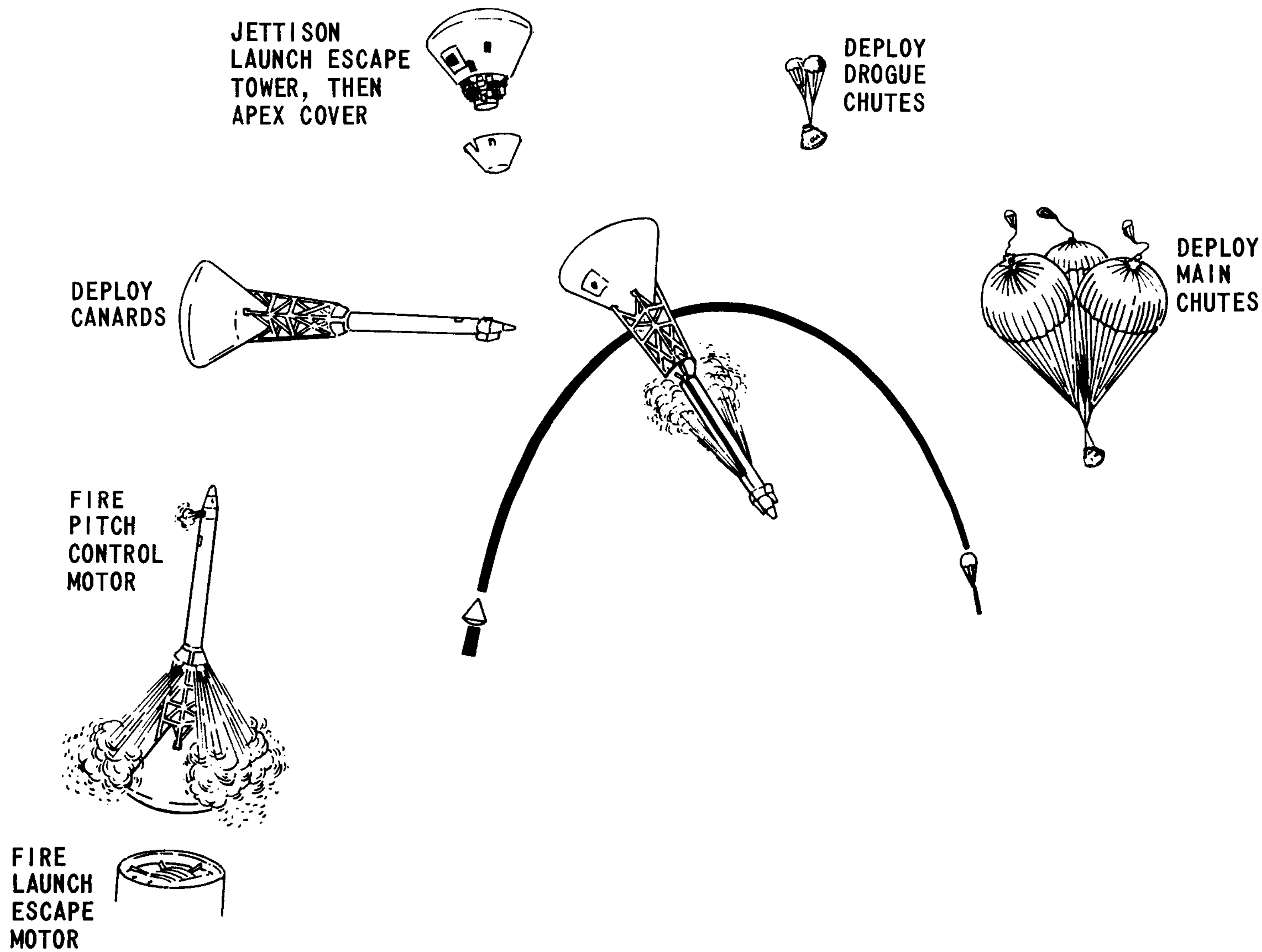


FIGURE 2 - EVENTS OCCURRING AFTER A NEAR-PAD ABORT

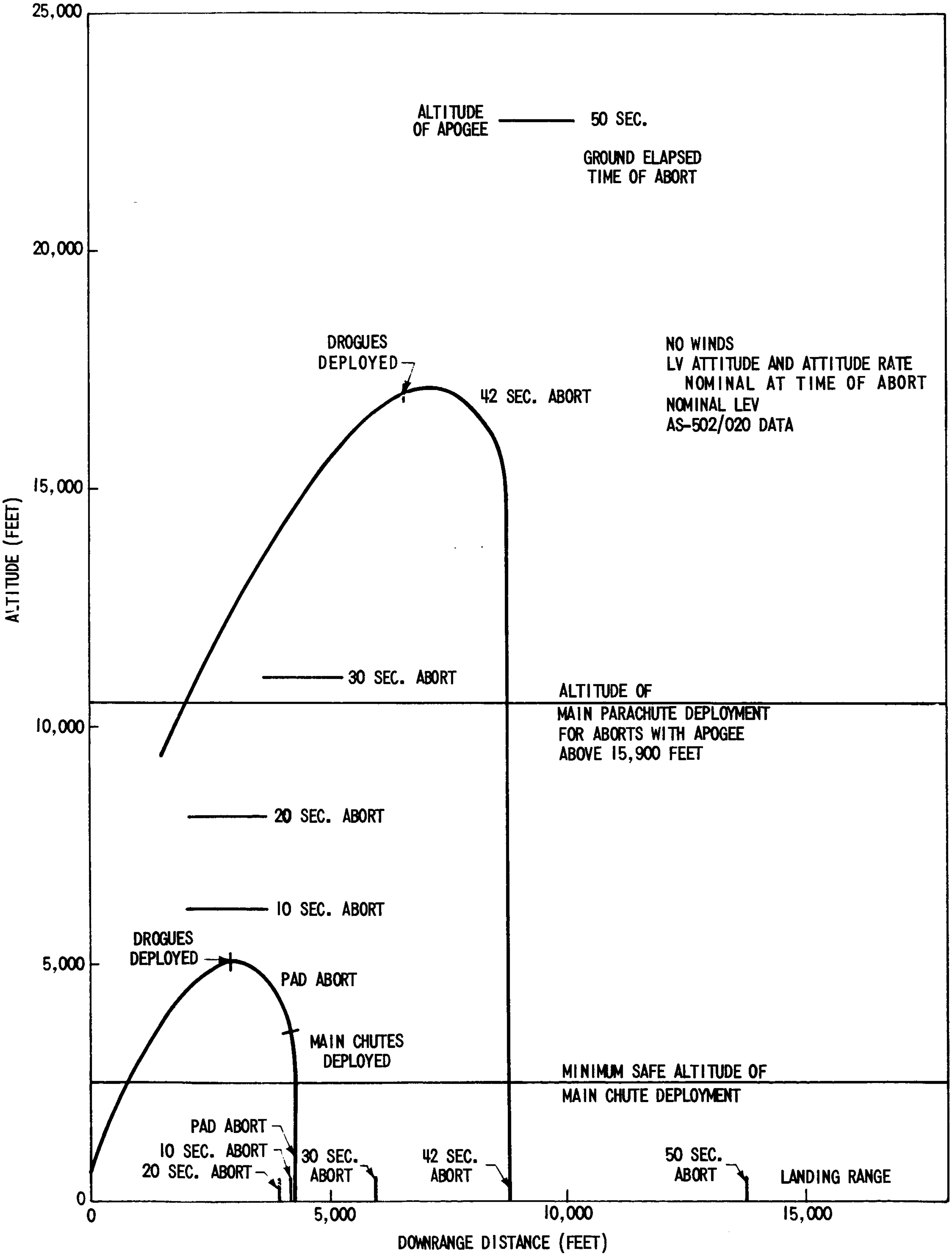


FIGURE 3 - TYPICAL LEV TRAJECTORIES (REFERENCE 8)

TIME OF ABORT (SECONDS)	NOMINAL RANGE (FEET) - APOLLO 7	CHANGE FROM THE NOMINAL LANDING POINT (FEET)[1] INITIATE ABORT AT UPRANGE TIPOVER ATTITUDE AND ATTITUDE RATE	INITIATE ABORT AT DOWNRANGE TIPOVER ATTITUDE AND ATTITUDE RATE	INITIATE ABORT AT RIGHT OR LEFT TIPOVER ATTITUDE AND ATTITUDE RATE	3σ LAUNCH ESCAPE MOTOR THRUST MISALIGNMENT	ANGLE OF UPRANGE - DOWNRANGE TIPOVER DIRECTION FROM NORTH (DEGREES)
10[2]	4,338	1,450	950	1,200	800	102
20	4,167	1,150	750	955	800	90
30	4,673	700	500	850	700	109
40	6,563	600	400	700	400	85
50	10,256	200	130	650	200	85

NOTES: 1. "TIPOVER" IN THE TRAJECTORIES BELOW INCLUDES 3σ THRUST MISALIGNMENT IN ADDITION TO INITIATING ABORT WITH AN ATTITUDE ERROR AND ATTITUDE RATE.

2. EXCEPT FOR RANGE, VALUES GIVEN FOR 10 SECOND ABORT ARE ASSUMED TO HOLD FOR PAD ABORT.

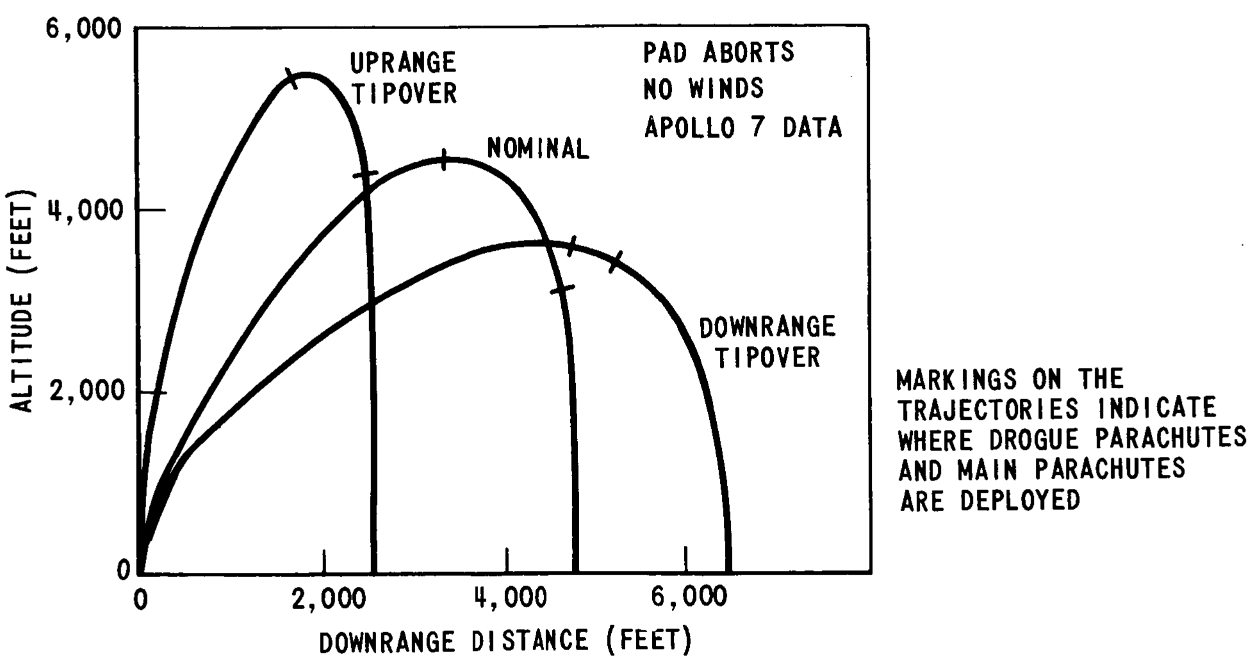
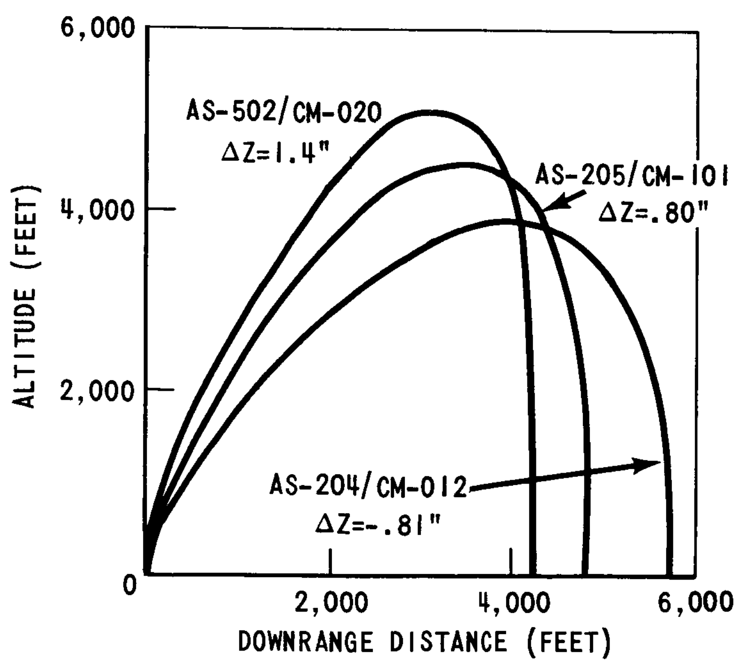


FIGURE 4 - LEV TRAJECTORIES WITH SATURN IB TIPOVER ATTITUDES AND ATTITUDE RATES (REFERENCES 7, 20 AND 21)

VEHICLE	WEIGHT OF LEV (POUNDS)	WEIGHT OF CM (POUNDS) AT MAIN PARACHUTE DEPLOYMENT INCLUDING RCS PROPELLANT
AS-502/CM-020	21,382	12,020
AS-205/CM-101	21,240	11,992
AS-204/CM-012	20,634	11,072



PAD ABORT
NO WINDS
NOMINAL LV ATTITUDE AND ATTITUDE RATE AT TIME OF ABORT
NOMINAL LEV

FIGURE 5 - COMPARISON OF LEV TRAJECTORIES IN THE OPERATIONAL ABORT PLANS (REFERENCES 4, 7, 8, 22, 23 AND 25)

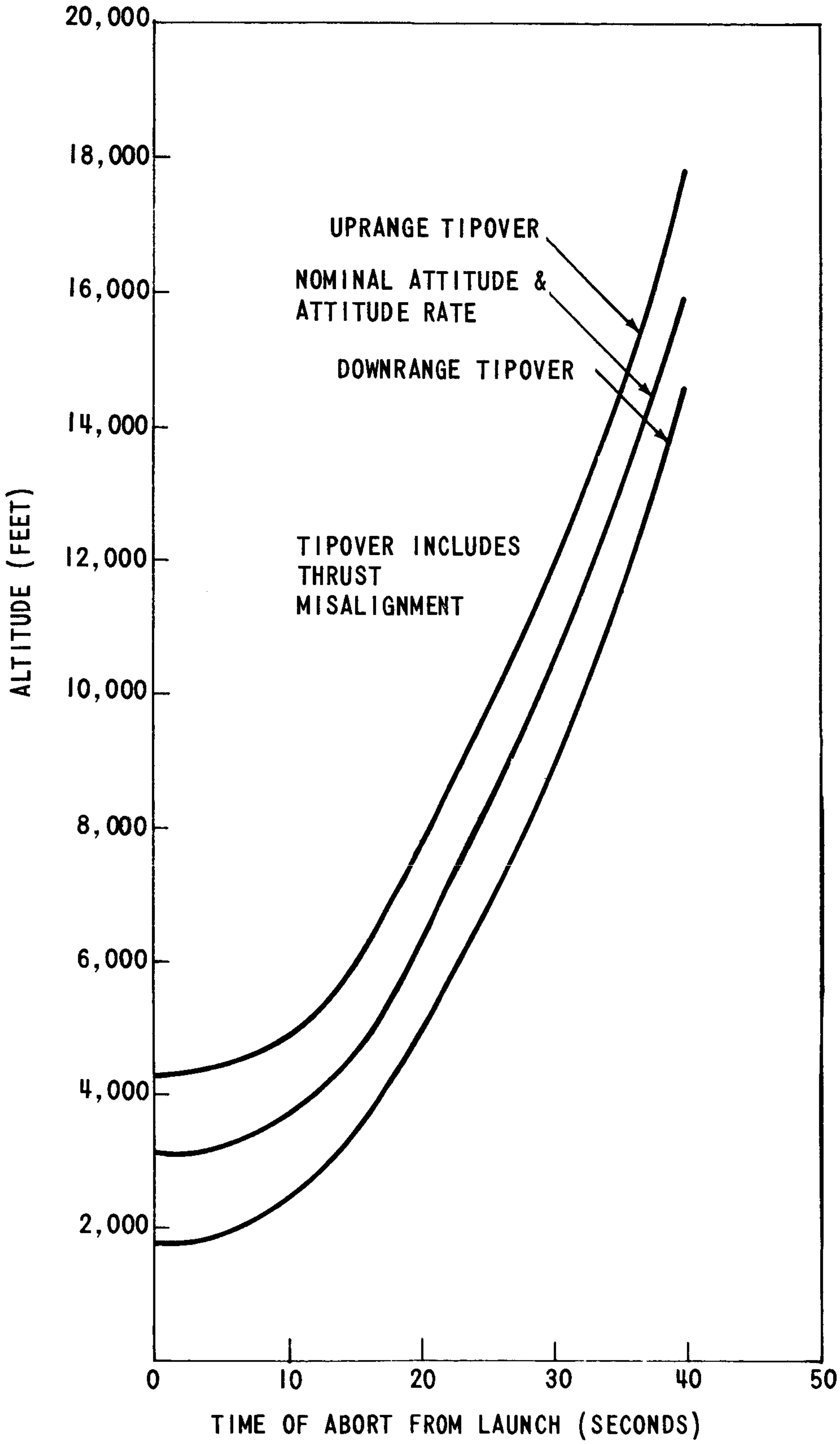


FIGURE 6 - ALTITUDE OF MAIN CHUTE DEPLOYMENT IF DEPLOYED AT 28 SECONDS AFTER ABORT (REFERENCES 1 AND 7)

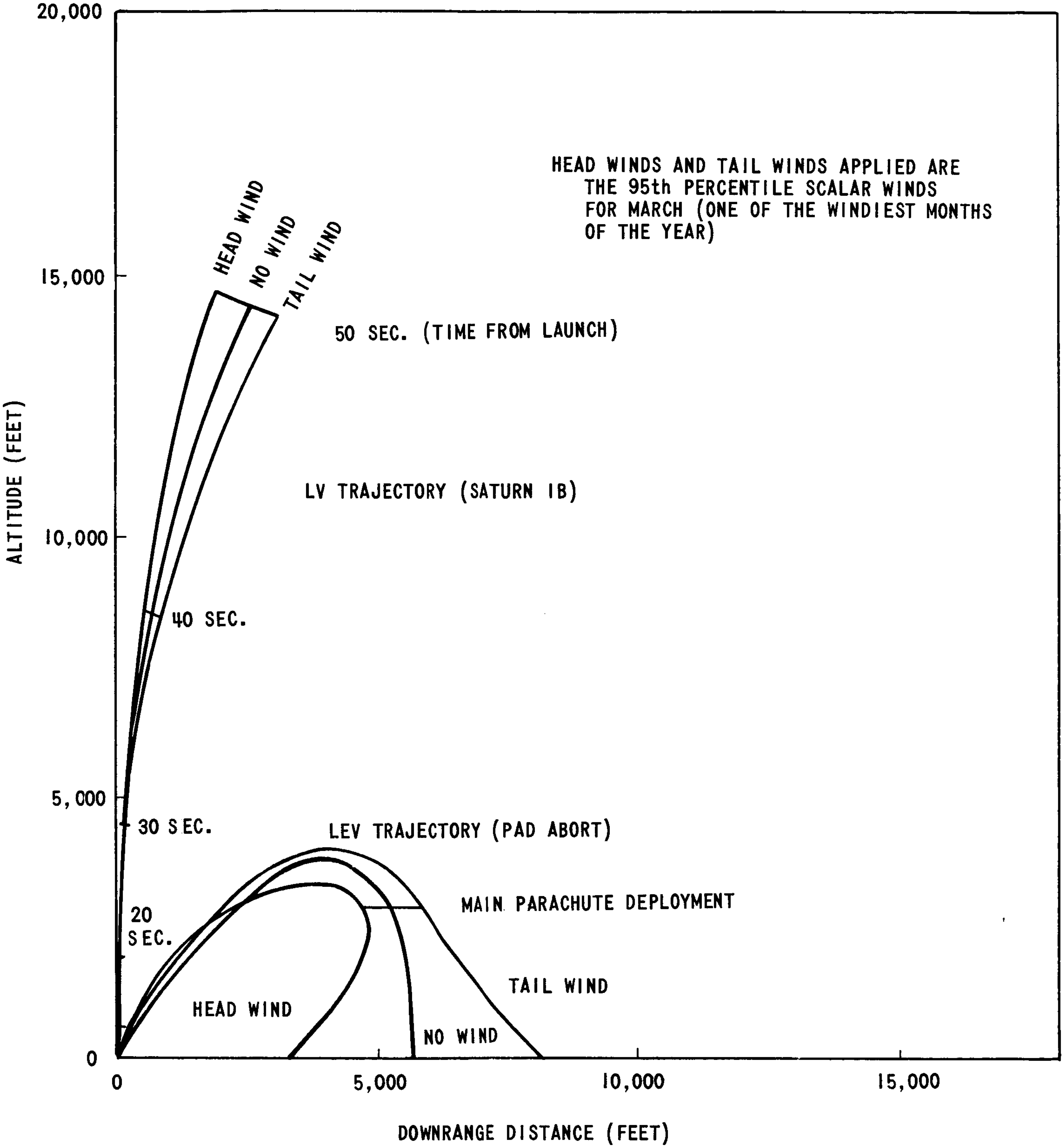


FIGURE 7 - EFFECT OF WIND ON THE LV AND LEV TRAJECTORIES (REFERENCES 27 AND 28)

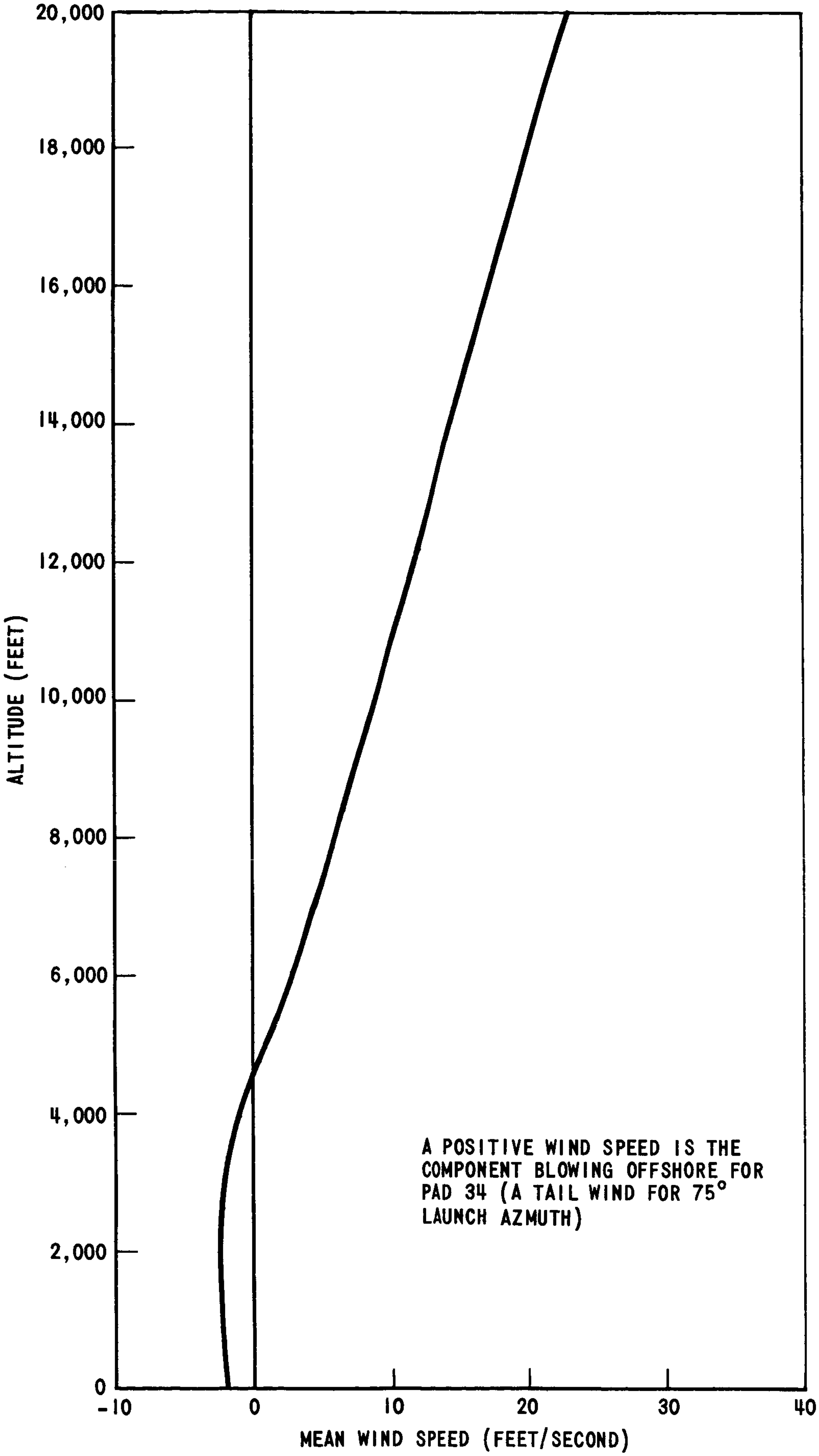


FIGURE 8 - MEAN ANNUAL OFFSHORE-ONSHORE WIND SPEED COMPONENT (REFERENCE 31)

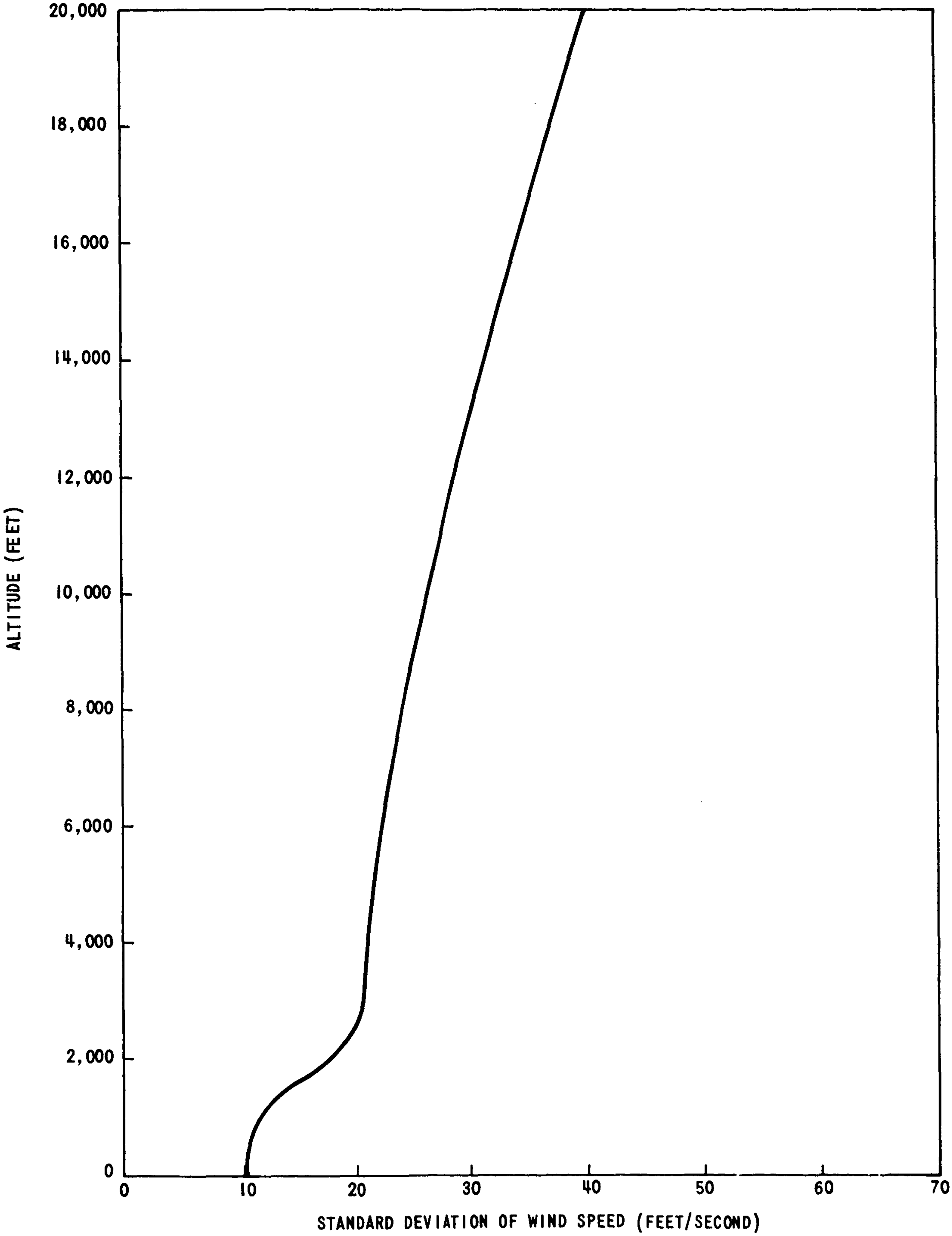


FIGURE 9 - STANDARD DEVIATION OF EAST-WEST WIND SPEED COMPONENT (REFERENCE 32)

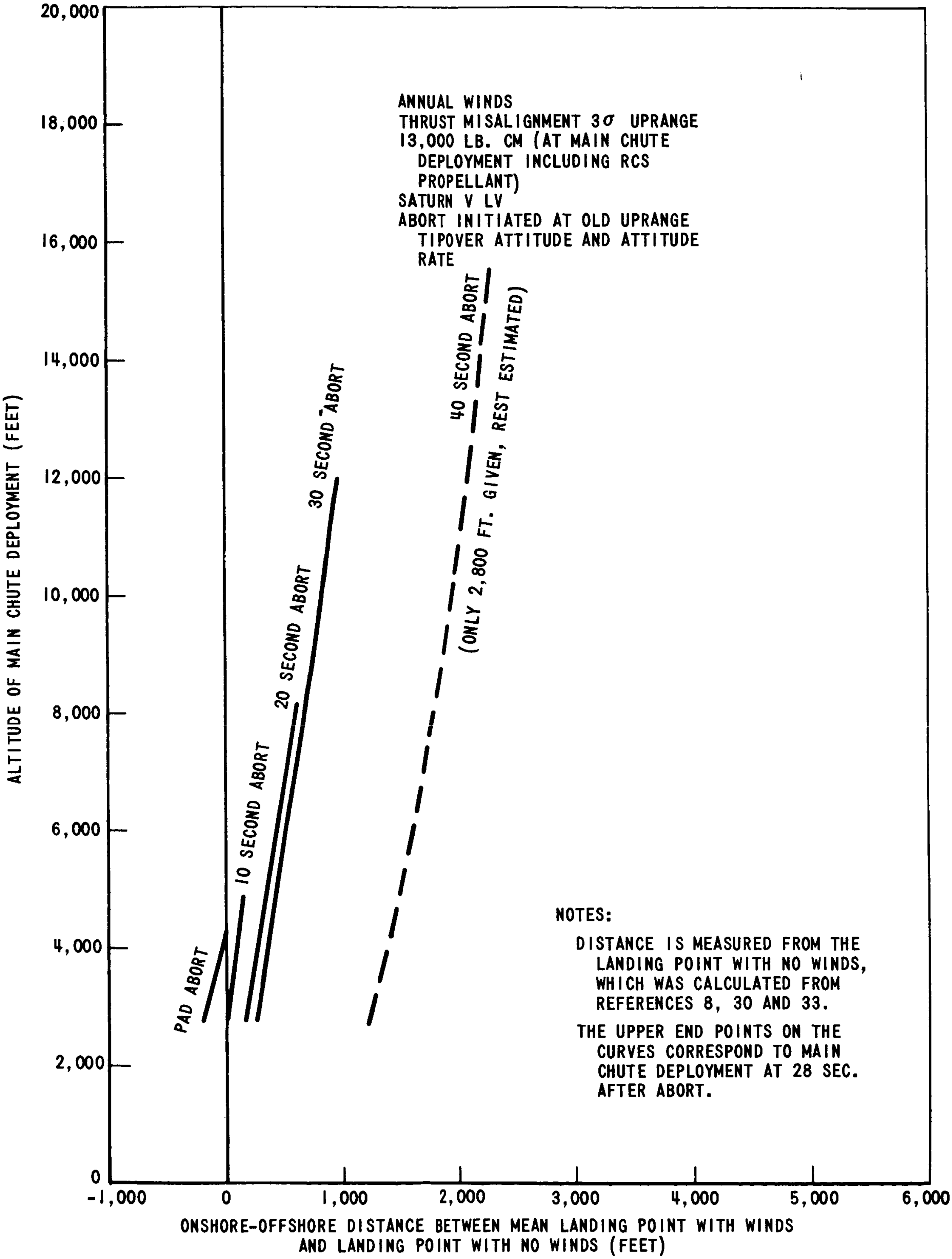


FIGURE 10 - RELATION OF THE MEAN LANDING POINT WITH WINDS APPLIED TO PARACHUTE DESCENT TO THE LANDING POINT WITH NO WINDS (REFERENCE 30)

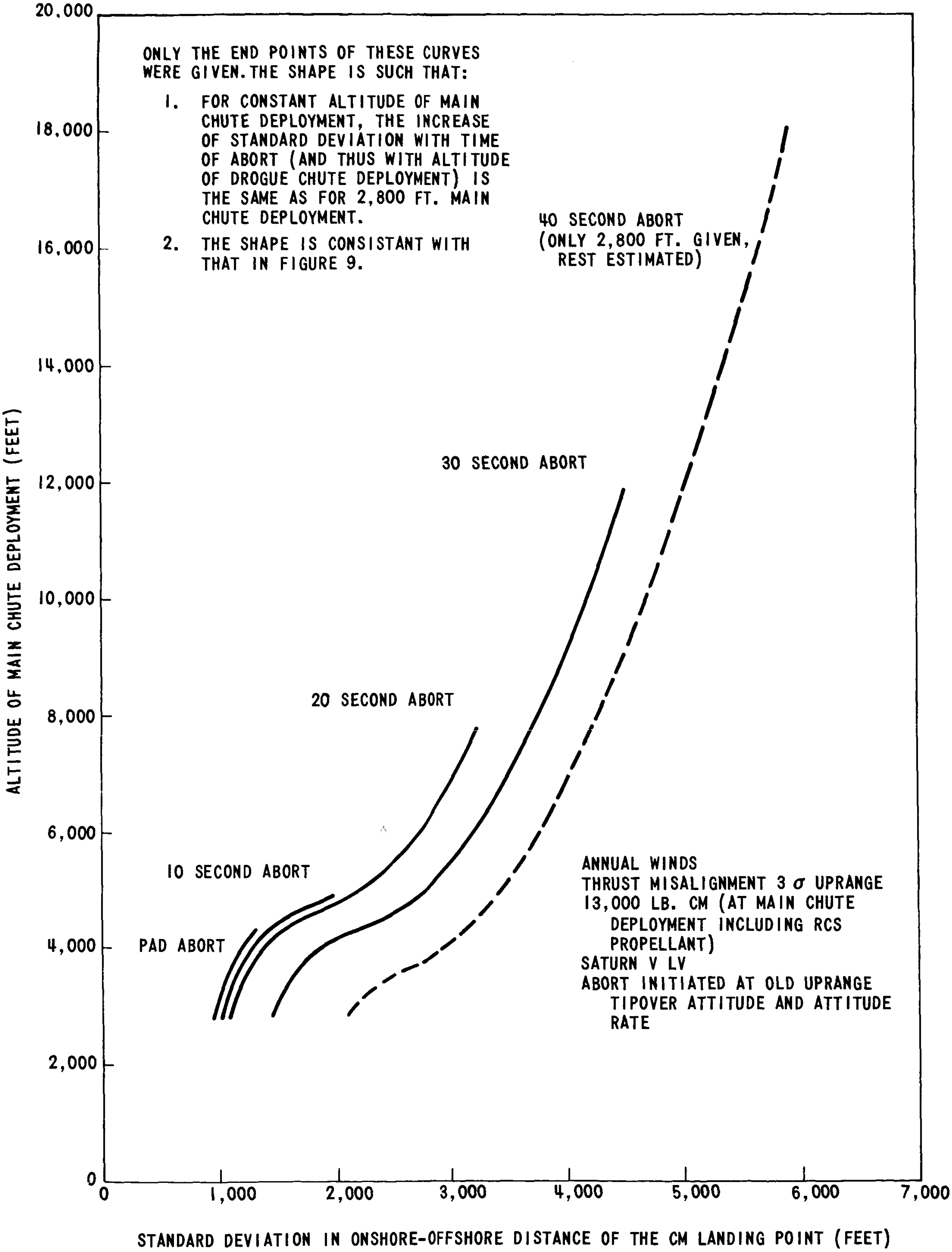


FIGURE 11 - STANDARD DEVIATION IN CM LANDING POINT BECAUSE OF WINDS APPLIED TO PARACHUTE DESCENT (REFERENCE 30)

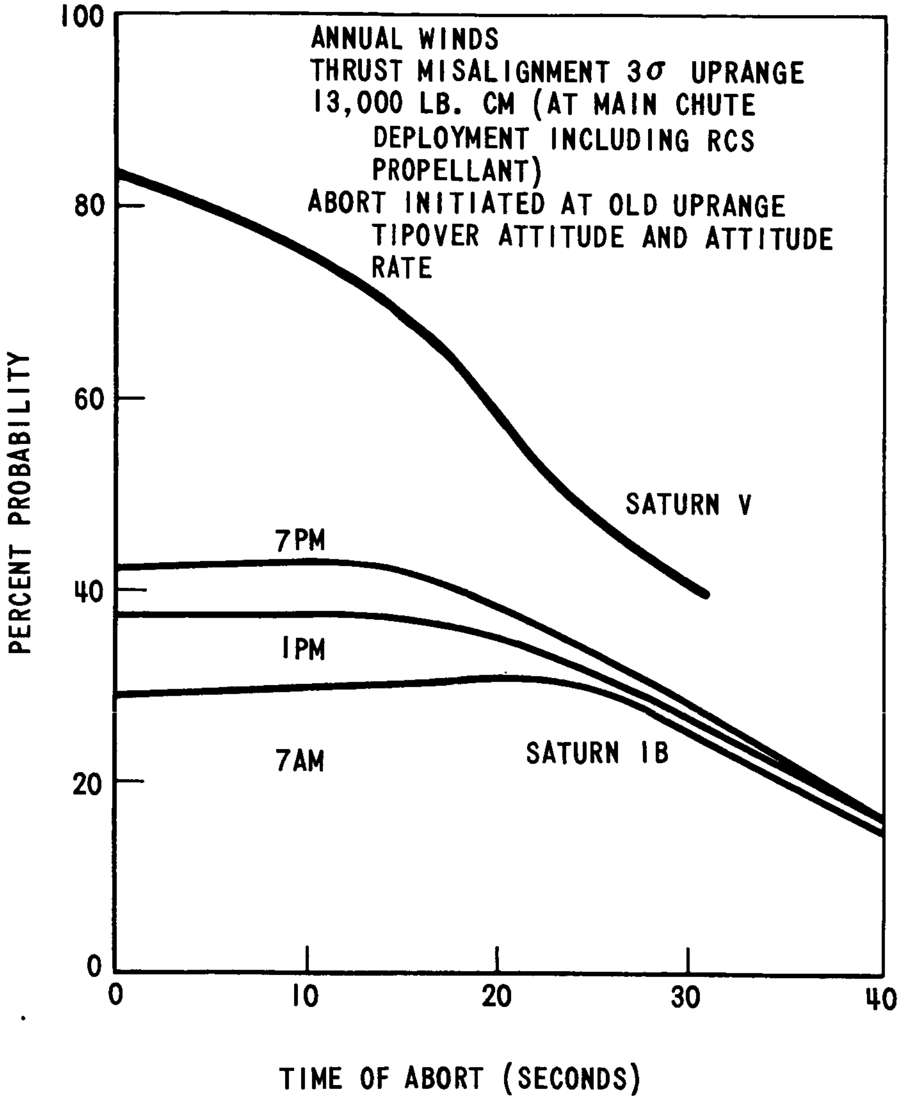


FIGURE 12 - MSC RESULTS ON LAND LANDING PROBABILITY (REFERENCES 30 AND 36)

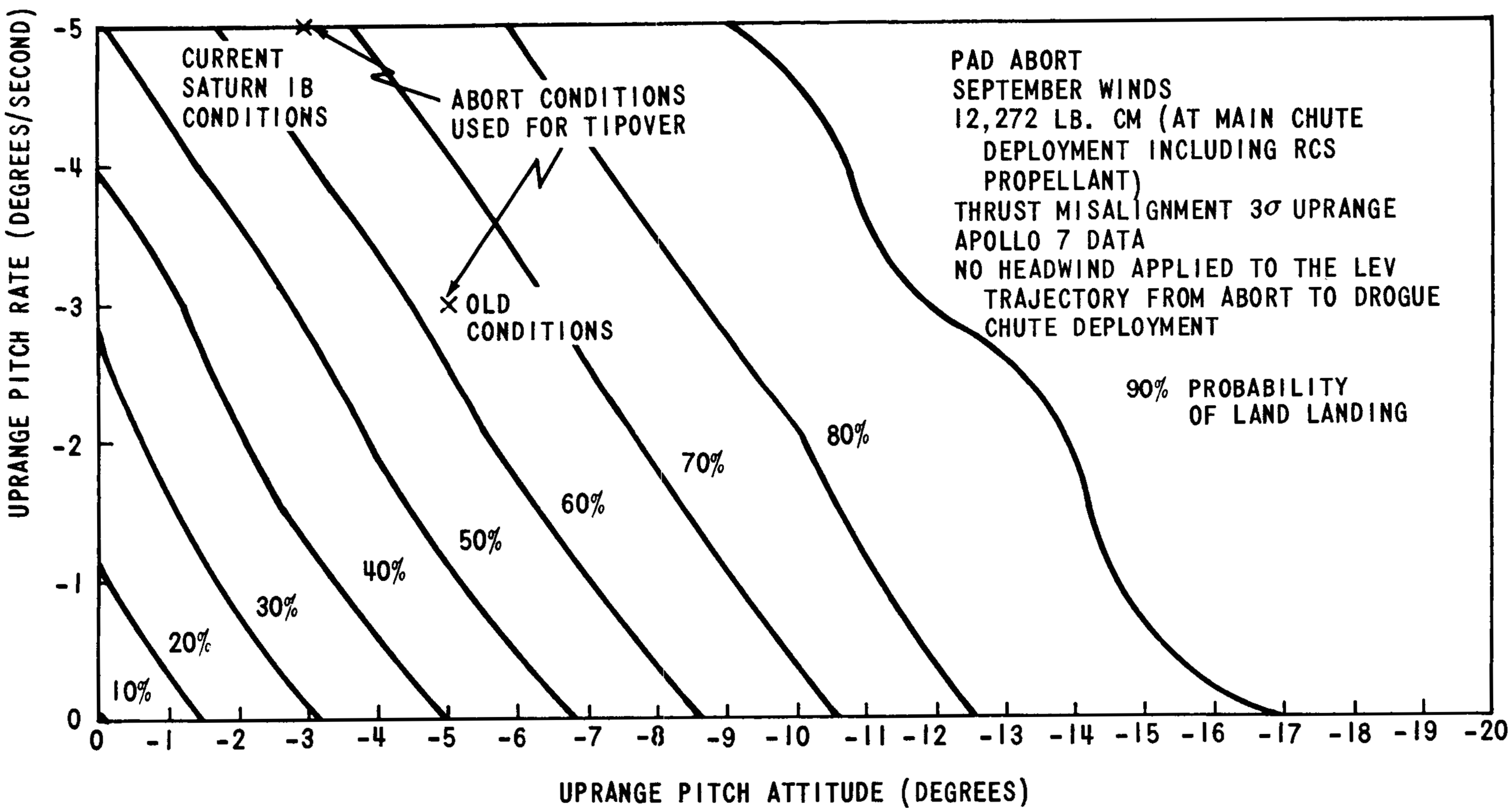


FIGURE 13 - EFFECT OF ATTITUDE AND ATTITUDE RATE AT ABORT INITIATION ON THE PROBABILITY OF LAND LANDING (REFERENCE 20)

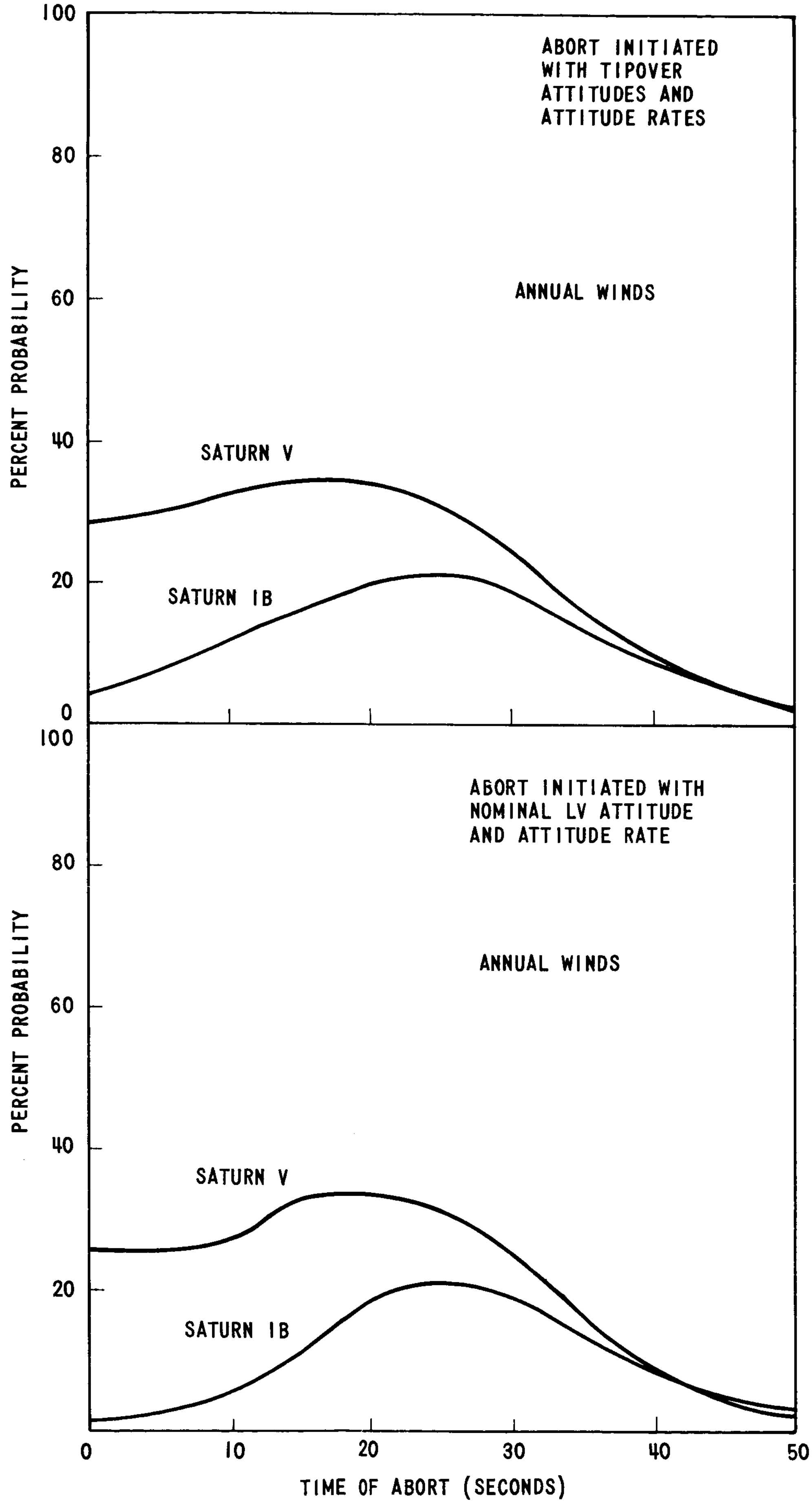


FIGURE 14 - LAND LANDING PROBABILITIES

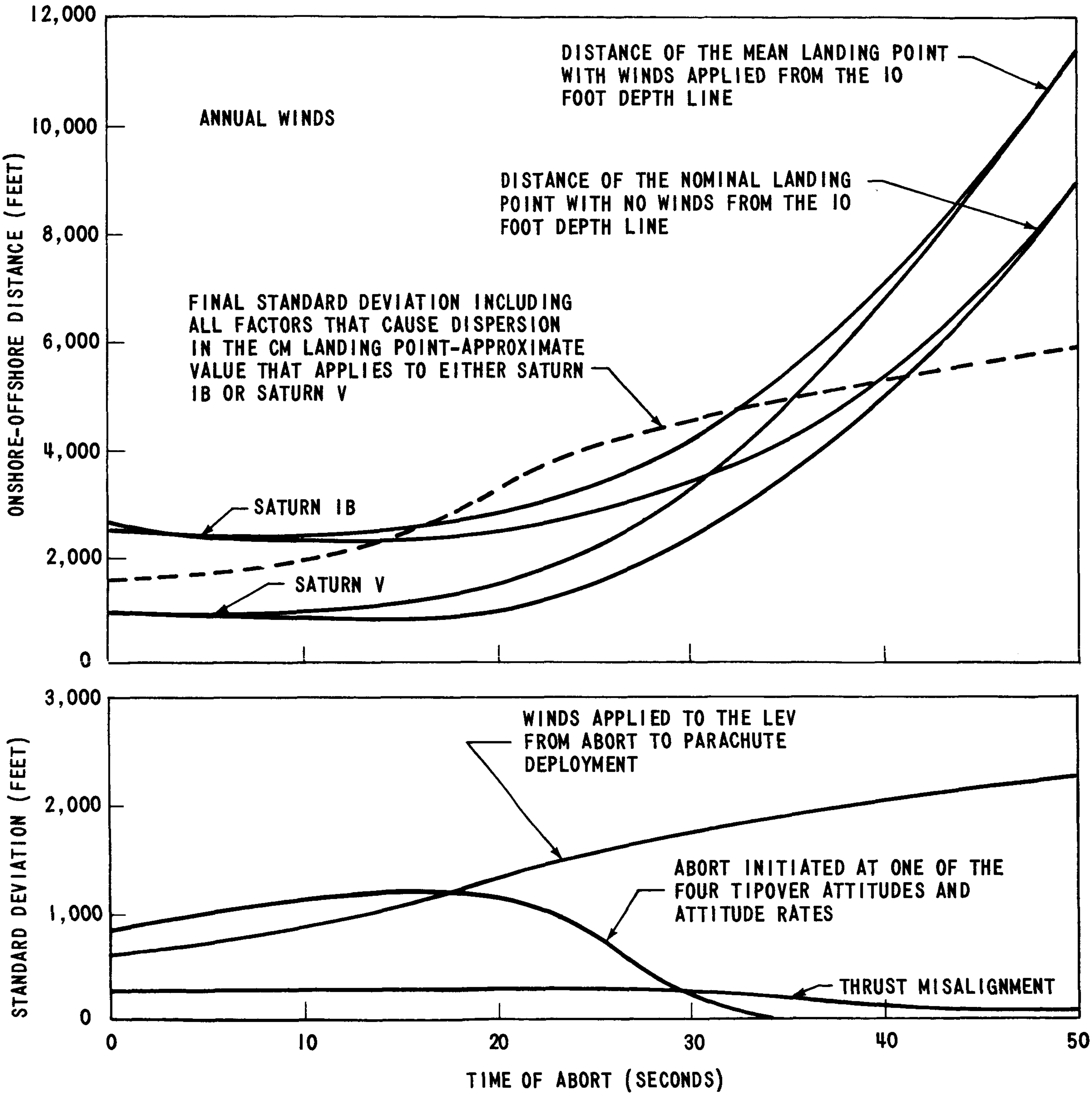


FIGURE 15 - COMPARISON OF THE FACTORS AFFECTING LAND LANDING PROBABILITY

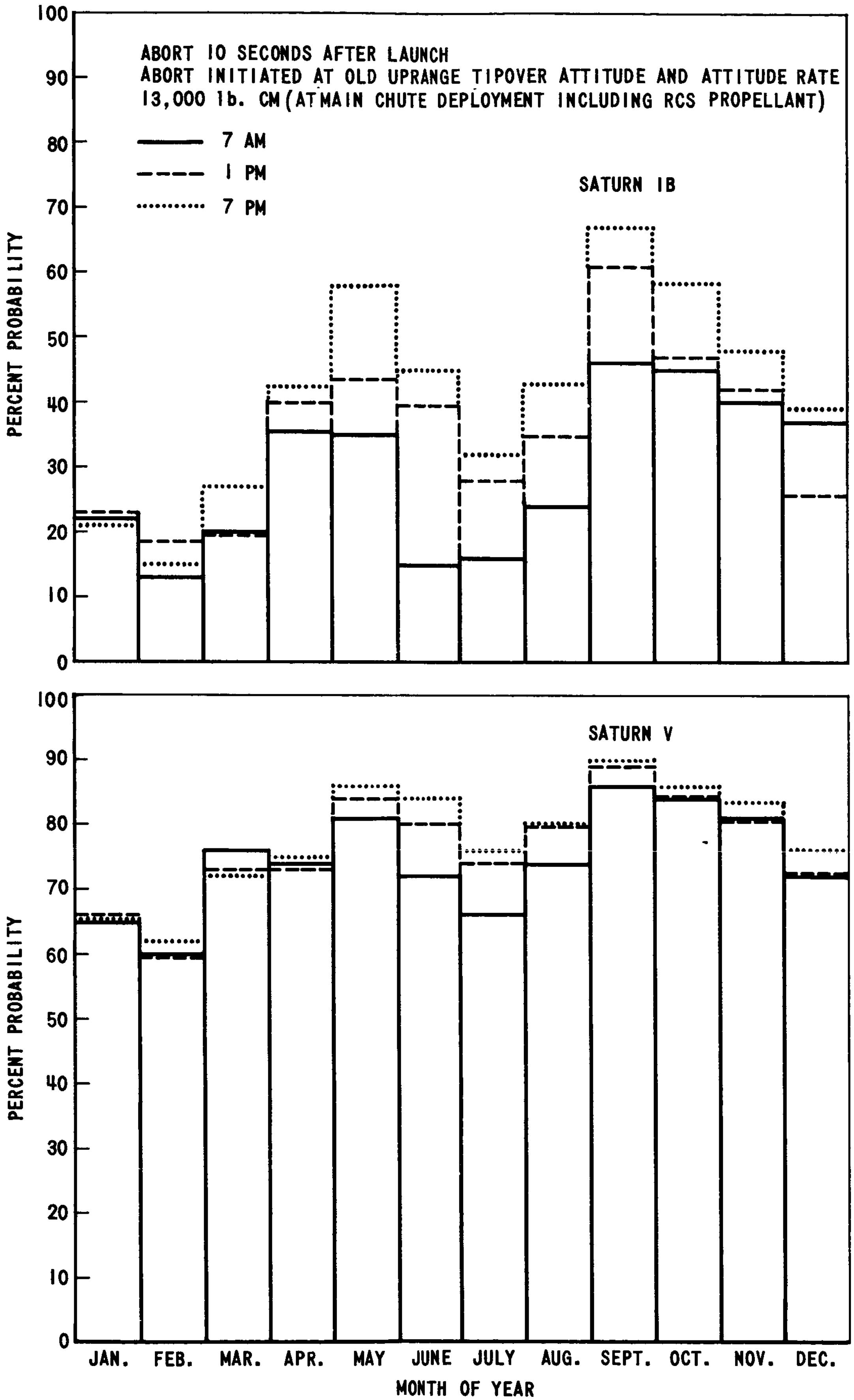


FIGURE 16 - VARIATION OF LAND LANDING PROBABILITY WITH MONTH OF YEAR AND TIME OF DAY (REFERENCES 36 AND 38)

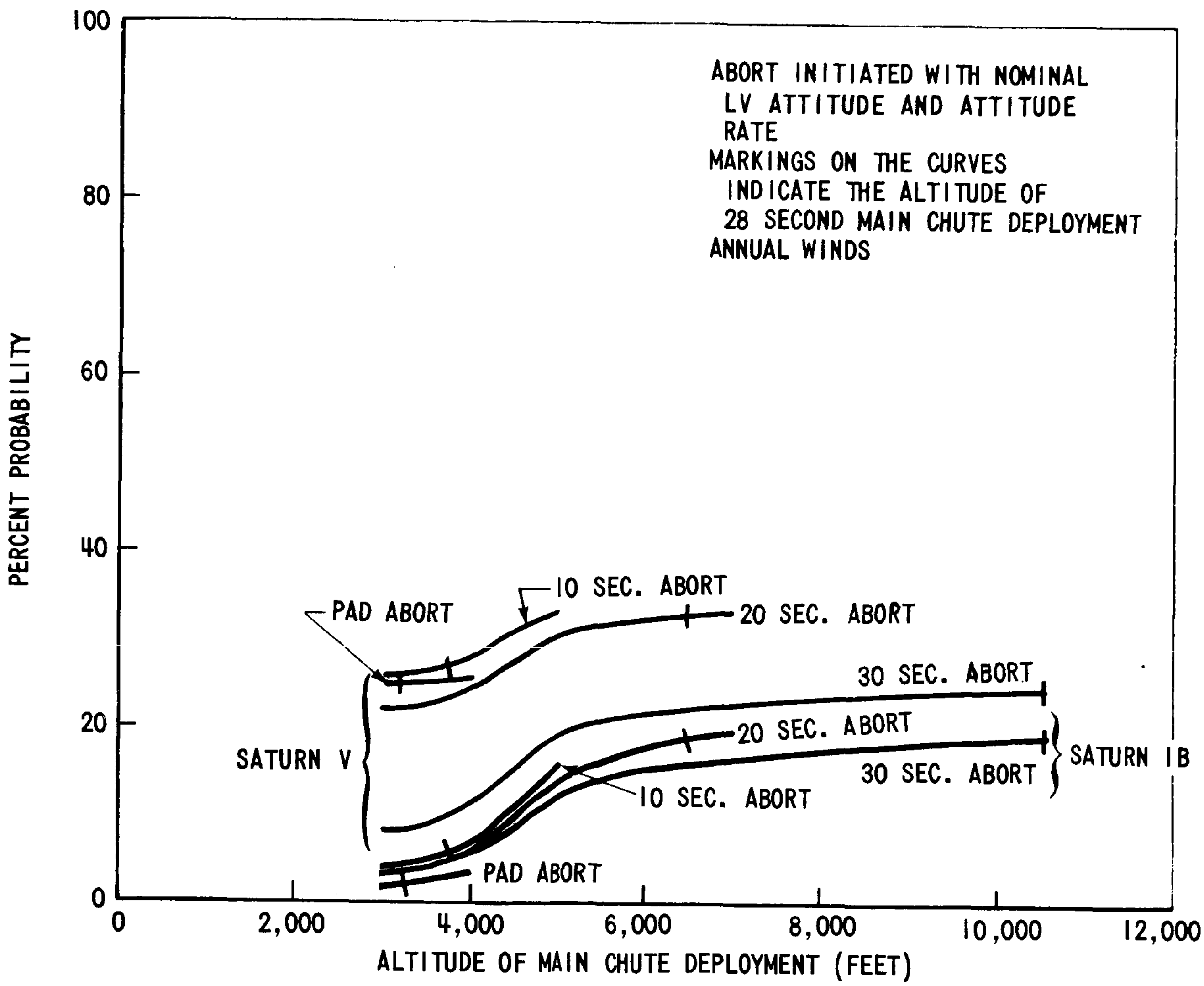


FIGURE 17 - SENSITIVITY OF LAND LANDING PROBABILITY TO ALTITUDE OF MAIN CHUTE DEPLOYMENT

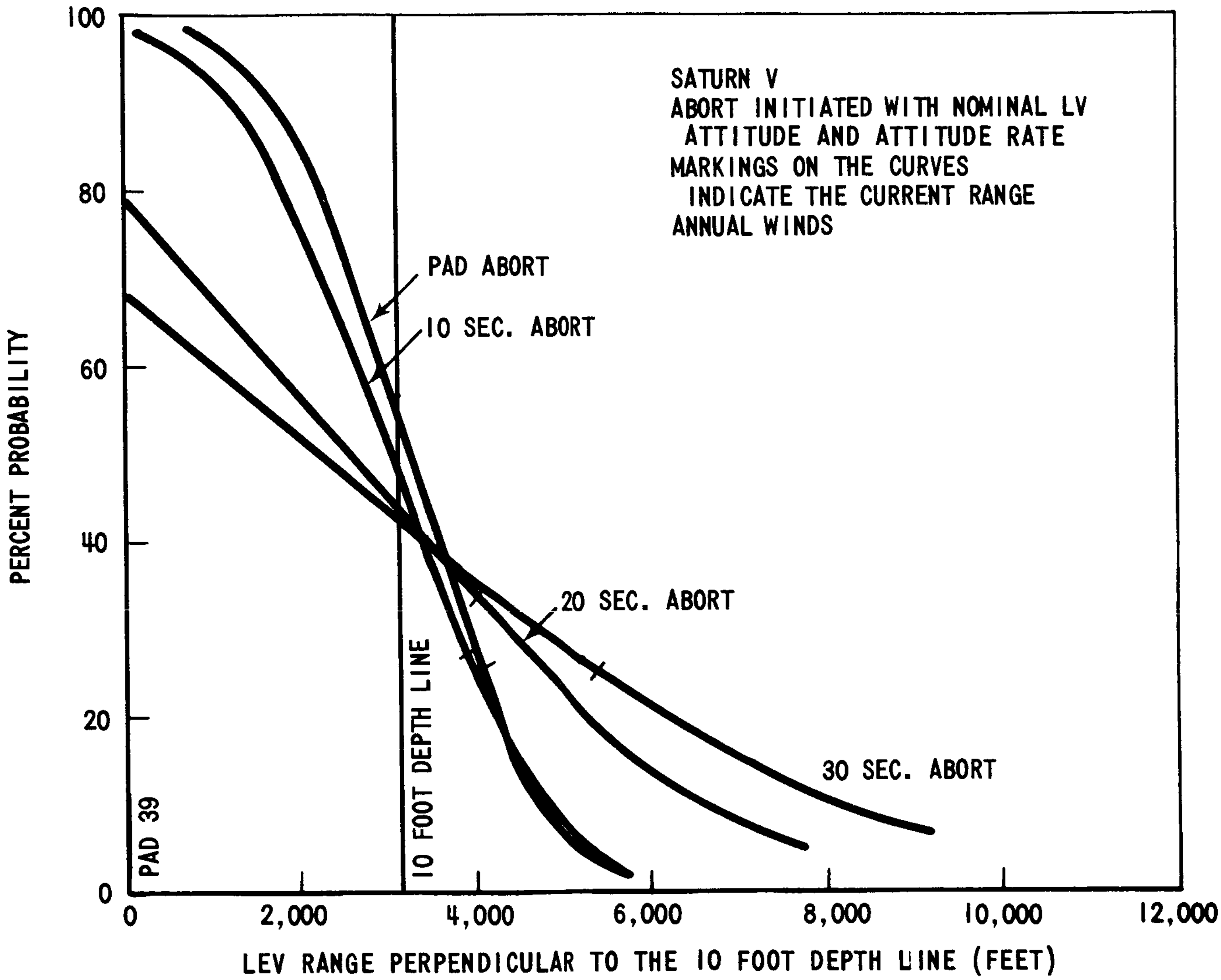


FIGURE 18 — SENSITIVITY OF LAND LANDING PROBABILITY TO LEV TRAJECTORY RANGE

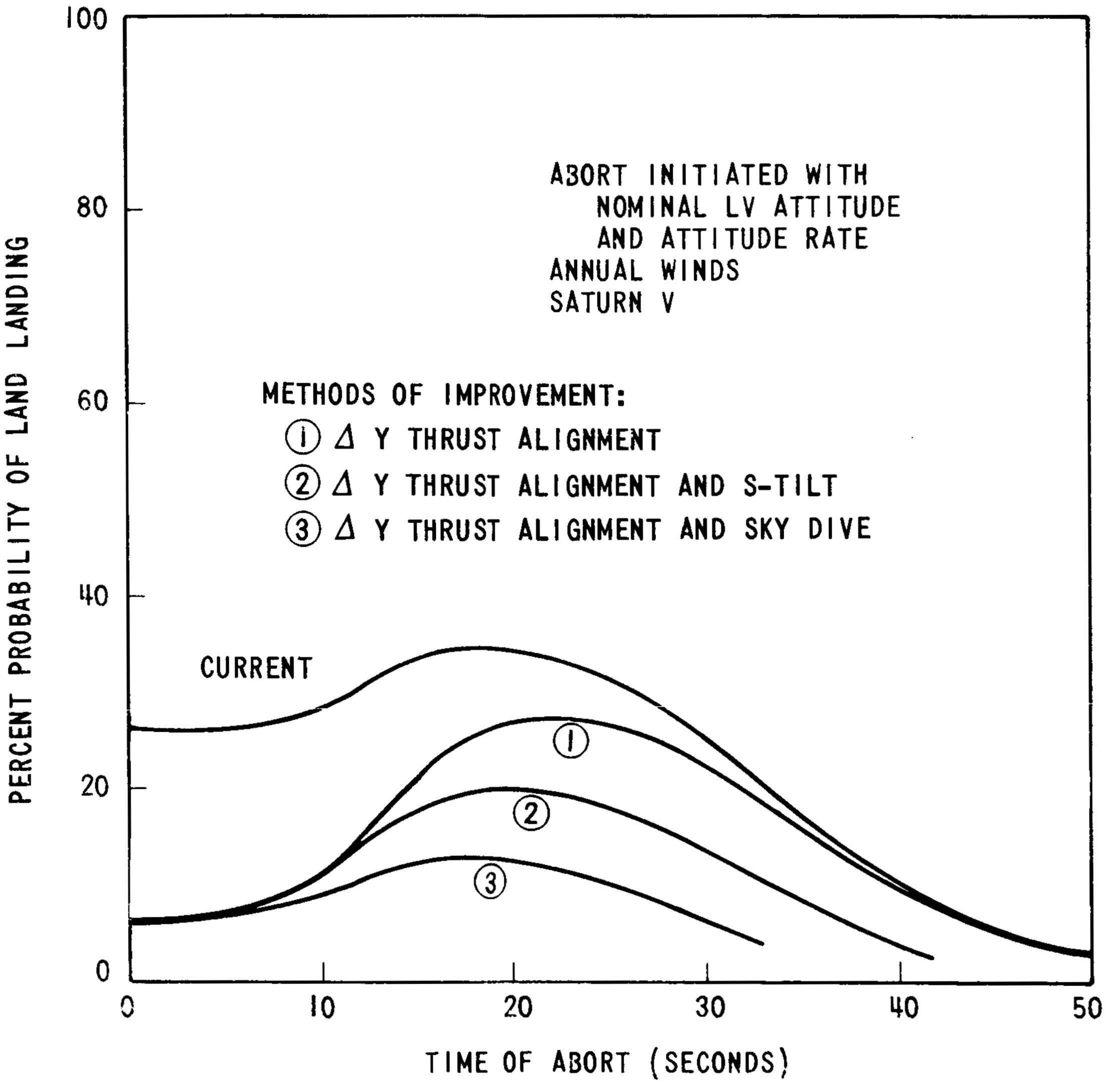


FIGURE 19 - EFFECT OF SUGGESTED METHODS OF IMPROVING SATURN V LAND LANDING PROBABILITY

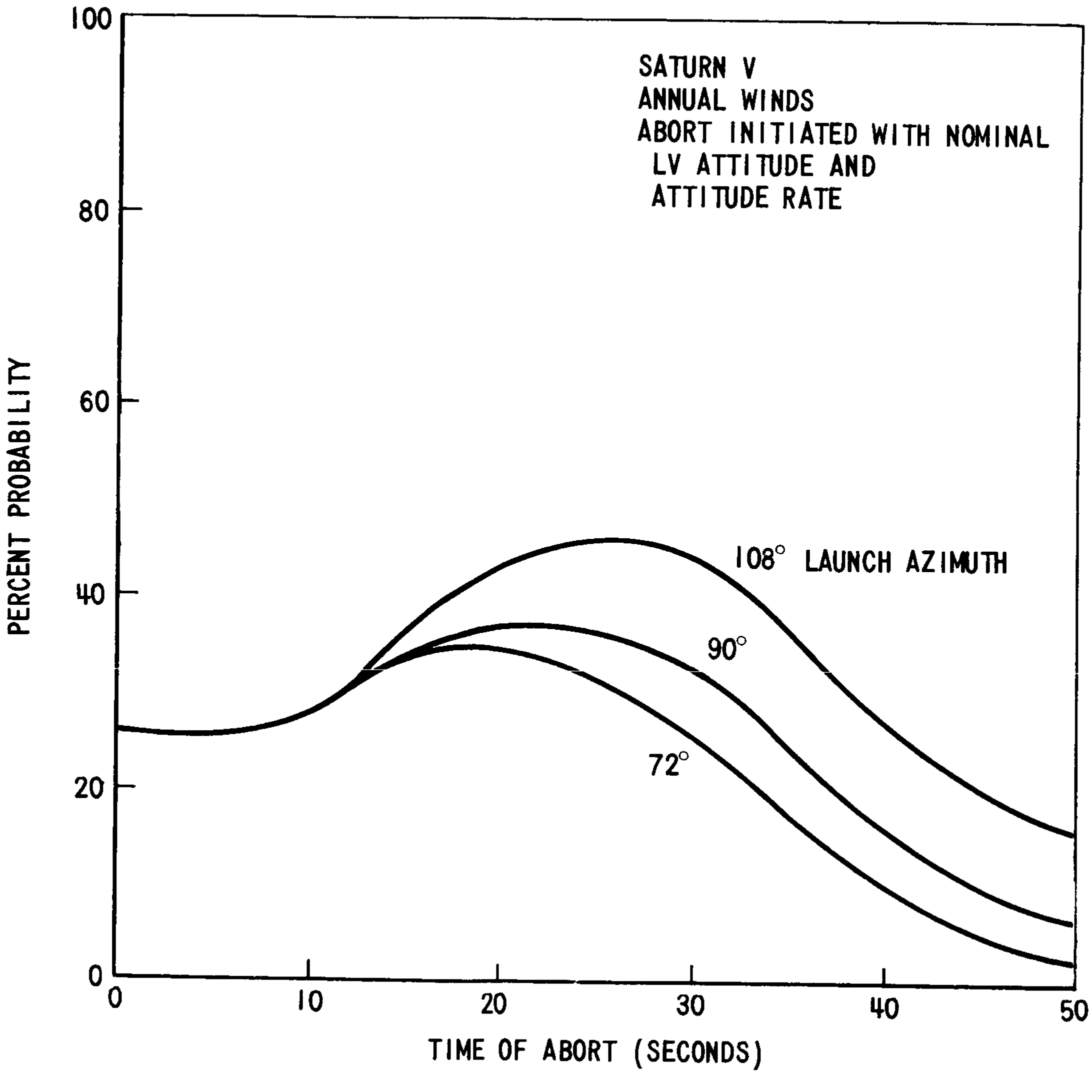


FIGURE 20 - EFFECT OF LAUNCH AZIMUTH ON LAND LANDING PROBABILITY

APPENDIX A

Sequence of Events After a Near-Pad Abort

In Table A1 a detailed list of the sequence of events that occur after a near-pad abort is given. The sequence is not exactly the same for all near-pad aborts as shown by the column that gives the condition that must be satisfied for an event to occur. For this reason it is convenient to divide LEV aborts into abort modes, although this terminology is not needed in this memorandum. LEV aborts are called Mode I aborts and these are divided into Mode IA, IB and IC aborts. The switching point between Modes IA and IB aborts is 61 seconds after launch for Saturn IB and 42 seconds after launch for Saturn V. Mode I aborts occurring after the LV reaches an altitude of 100,000 feet (at about 108 seconds after launch) are called Mode IC aborts.

APPENDIX B

Methods of Obtaining Statistical Results On the Effect of Winds on LEV Trajectories

Three methods have been proposed [52] to obtain statistical results on the effect of winds on LEV trajectories: wind profile constraint, statistical model and flight simulation. This last method is the one used by MSC and is described in the body of this memorandum. The first two are discussed below.

1. Wind Profile Constraint

If a simple description of the wind profile constraint that must be imposed to avoid land landing can be given, the probability of winds being worse than this can be found simply from wind data. In setting a constraint only pad aborts and aborts up to 15 seconds were considered so the maximum altitude reached by LES trajectories is about 8000 feet, even with uprange tipover. Wind data available in this region is at 0, 1 and 2 kilometers (0,3281 and 6562 feet); this data is from surface measurements taken every hour and from Rawinsonde measurements taken regularly at 7:00 A.M. and 7:00 P.M. and sometimes at 1:00 A.M. and 1:00 P.M. The first constraint which was used to generate probabilities from wind data required that wind from directions 60 to 120 degrees at all of the three altitudes be less than 4 meters/second (13.1 feet/second); the direction requirement was later changed to 0 to 180 degrees and the speed changed to 1 meter/second (3.3 feet/second). This constraint is not too reasonable because it should really be the onshore component of the wind that is restricted and because wind at one altitude could cause a constraint condition independent of winds at other altitudes (surface and inflight winds are not highly correlated). More recently for Pad 34 launches a constraint of 1 foot/second on the wind component from 72 degrees azimuth was used [53 and 54]; instead of requiring the wind at all three altitudes (0,1 and 2 kilometers) to meet this constraint, the constraint was applied to the sum of the weighted wind speeds, where the weighting factors were 1/4 for the 500 meter surface layer (0 to 1,640 feet), 1/2 for the next 1 kilometer layer (1,640 to 4,921 feet)(this layer is weighted twice as much as the previous layer because it is twice as thick), and 1/4 for the last 1 kilometer layer (4,921 to 8,202 feet) (this layer is weighted 1/4 because the main parachutes are deployed at lower altitudes). The 1 foot/second limit is reasonable for worst case considerations (uprange tipover and 95th percentile headwinds applied to the LEV trajectory) as shown in Figure A1. The only application of this constraint that has been made so far was to determine how much the probability of land landing with uprange tipover varies with time of the day. It was shown that this variation is small for the months of October and November [55]; in Reference 44 for mid-September to mid-October and the same conclusion is indicated.

2. Statistical Model

Annual wind data has been statistically reduced to give the mean and standard deviation for each altitude and component and the correlations between altitudes and components [32]. By applying these statistics to an LEV trajectory simulator it would be possible to derive the density function of CM landing points and therefore land landing probabilities. In Reference 52 a method that has been used in other applications is suggested but not described (this method uses "ballistic factors" and the results are gotten simply by matrix multiplication), although according to Reference 1 this method is not applicable to parachute descent.

APPENDIX C

Description of Wind Data Used in Trajectory Simulations

The wind data used by the Analytical Aerodynamics Section, MSC, to calculate land landing probabilities was obtained from the U. S. Weather Bureau National Weather Records Center in Asheville, North Carolina. The data was taken over an eight year period (1956 through 1964). All except approximately the first year of this data was taken at KSC; the rest of the data was from Partick Air Force Base which is near KSC. Approximately 15,000 wind profiles were available, but after these were edited to obtain profiles with data at each 1 kilometer level up to 20,000 feet, only 9,928 remained. Of these profiles, about 8,000 consisted of almost complete data for 7:00 A.M. and 7:00 P.M., about half complete data for 1:00 P.M. and somewhat less than half for 1:00 A.M.; the rest of the profiles were taken at other times. In general those days when the 7:00 A.M. or 7:00 P.M. data was not available were when unusually high winds occurred (this has been shown in References 56 and 57 by filling in the missing data in the above set of profiles by interpolation; this serially complete set of profiles is the data used by the Terrestrial Environment Branch, MSFC). On the other hand, one should eliminate those profiles that violate the LV structural wind constraint (scalar wind greater than the 95th percentile peak surface wind or the 95th percentile quasi-steady state inflight winds during the strongest wind month). A study has shown [37] that most of those profiles that would be eliminated would cause water landing. Therefore, MSFC's serially complete data would lead to the lowest land landing probabilities, MSC's data would lead to higher land landing probabilities and data with profiles eliminated that violate the LV wind constraint would lead to the highest probabilities, although there is no indication whether the difference would be significant.

APPENDIX D

Example of the Calculations Required to Find the Land Landing Probability

As an example of the calculations used to establish a point in Figure 14 consider a Saturn IB pad abort with abort initiated at the tipover attitudes and attitude rates. First the standard deviations of the distribution functions for winds applied to parachute descent shown in Figure A2 must be estimated by considering the deviations at 0.13% (-3σ), 2.28% (-2σ), 15.87% (-1σ), etc. The results were given in Figure 11. A comparison of the empirical and normal distribution functions is shown in Figure A3. When the right half of a distribution curve was not symmetric with the left half, the standard deviation was estimated from the left half because in most cases this is the part of the curve that will be used in finding land landing probabilities.

The altitude of main chute deployment, if deployed at 28 seconds after abort, was given Figure 6. Because these curves included thrust misalignment it was assumed that aborting at the downrange and uprange attitude and attitude rate would give about the same altitudes of main chute deployment as shown in Figure 6 for downrange and uprange tipover, respectively; also that aborting at the right or left tipover attitude and attitude rate would give about the same altitudes as shown for no tipover. For pad abort with abort at the uprange tipover attitude and attitude rate the altitude of main chute deployment would be 4,300 feet. For abort at the downrange, right or left tipover attitude and attitude rate the main chutes would be deployed early at 3,300 feet (altimeter setting for minimum altitude of main chute deployment). From Figure 11 these correspond to standard deviation of 1,300 feet and 1,000 feet, respectively, for winds applied to parachute descent.

To account for winds applied to the LEV trajectory from abort to parachute deployment, we must add to these the standard deviation given in Table 2 on page 10: this is 170 feet for pad abort. Therefore the standard deviation in the CM landing point for winds applied to the entire LEV trajectory from abort to touchdown is 1,470 feet for abort at the uprange tipover attitude and attitude rate and 1170 feet for abort at the downrange, right or left tipover attitude and attitude rate.

Considering data with no winds applied, the relation of the landing points for abort at the tipover attitudes and attitude rates to the landing point for abort from a nominal LV must now be calculated. The result must be expressed in terms of onshore-offshore distance. Noting the results given in the table in Figure 4 for 10 second abort also apply for pad abort, the angle between the uprange-downrange tipover direction and north is 102°; since the perpendicular to the 10 foot depth line for Pad 34 is 70° from north, the angle between the uprange-downrange tipover direction and the perpendicular to the 10 foot depth line is 32°. Projecting the changes from the nominal landing point also shown in the table in Figure 4 on the perpendicular to the 10 foot depth line gives -1,230 feet for abort at the uprange tipover attitude and attitude rate, +805 feet for the downrange tipover attitude and attitude rate and $\pm$635 feet for the right or left tipover attitude and attitude rate. If winds are applied to these trajectories the mean landing point is different from these values as given by Figure 10. We now have -1,230 feet, +660 feet, +490 feet and -780 feet, respectively. These values are used for the means of the distribution functions plotted in the lower half of Figure A4. The standard deviations used to plot these curves were those values found in the previous paragraph. Assuming abort in each direction to be equally likely, the sum of 1/4 of each of these distribution functions was found, and the result shown in the top half of Figure A4.

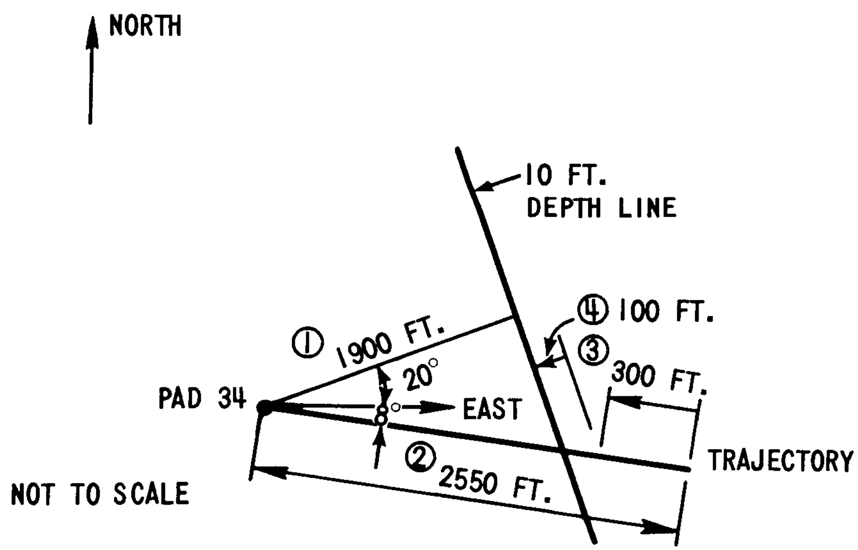
Assuming this result is normal, the standard deviation and the distance of the mean from the nominal landing point are seen from this figure to be 1,500 feet and -180 feet, respectively. The standard deviation must be finally root-sum-squared with the standard deviation due to thrust misalignment given in the table of Figure 4 (267 feet), to give 1,525 feet. From Table 1 on page 4, it is seen that the 10 foot depth line is -2650 feet from the nominal landing point, so it is -2470 feet from the mean landing point. In units of the standard deviation given above this is -1.74σ and from a table of the normal distribution function this yields a final result of 4.1% land landing probability.

TABLE AI

SEQUENCE OF EVENTS AFTER A NEAR-PAD ABORT
(REFERENCES 1, 3, 4, 50 AND 51)

<table>
<tr><th rowspan="2">TIME (SECONDS) FROM ABORT OR ALTITUDE (FEET)</th><th rowspan="2">CONDITION (T_a = TIME AFTER LAUNCH OF ABORT)</th><th rowspan="2">EVENT</th><th colspan="2">INITIATION</th></tr>
<tr><th>AUTOMATIC</th><th>MANUAL OR MANUAL BACKUP</th></tr>
<tr><td>.006</td><td>40 SEC. $< T_a$ (SATURN IB)
30 SEC. $< T_a$ (SATURN V)</td><td>CUT OFF LAUNCH VEHICLE ENGINE[1]</td><td>✓</td><td>✓</td></tr>
<tr><td>.124</td><td></td><td>CM-SM SEPARATION</td><td>✓</td><td>✓</td></tr>
<tr><td>.130</td><td></td><td>FIRE LAUNCH ESCAPE MOTOR[2]</td><td>✓</td><td>✓</td></tr>
<tr><td>.136</td><td rowspan="4">$T_a <$ 61 SEC. (SATURN IB)
$T_a <$ 42 SEC. (SATURN V)</td><td>FIRE PITCH CONTROL MOTOR[3]</td><td>✓</td><td>✓</td></tr>
<tr><td>.024</td><td>DUMP RCS OXIDIZER</td><td>✓</td><td>✓</td></tr>
<tr><td>5.024</td><td>DUMP RCS FUEL</td><td>✓</td><td>✓</td></tr>
<tr><td>18.034</td><td>PURGE RCS HELIUM</td><td>✓</td><td>✓</td></tr>
<tr><td>11.018</td><td></td><td>DEPLOY CANARDS</td><td>✓</td><td></td></tr>
<tr><td>14.030</td><td></td><td>JETTISON LAUNCH ESCAPE TOWER AND BOOST PROTECTIVE COVER</td><td>✓</td><td>✓</td></tr>
<tr><td>14.036</td><td></td><td>JETTISON LM DOCKING RING</td><td></td><td>✓</td></tr>
<tr><td>14.430</td><td></td><td>JETTISON APEX COVER</td><td>✓</td><td>✓</td></tr>
<tr><td>16.042</td><td></td><td>DEPLOY DROGUE PARACHUTES[4]</td><td>✓</td><td>✓</td></tr>
<tr><td>$>$16.042 AND ~ 3300 FT.[5]</td><td></td><td rowspan="3">RELEASE DROUGE CHUTES AND DEPLOY PILOT CHUTES[8]</td><td></td><td>✓</td></tr>
<tr><td>28.036</td><td>ABORT APOGEE $<$ 15900 FT[7]</td><td>✓</td><td>✓</td></tr>
<tr><td>10500 FT.[6]</td><td>15900 FT. $<$ ABORT APOGEE[7]</td><td>✓</td><td>✓</td></tr>
<tr><td>AFTER MAIN CHUTE DEPLOYMENT</td><td rowspan="2">61 SEC. $< T_a$ (SATURN IB)
42 SEC. $< T_a$ (SATURN V)</td><td>BURN RCS PROPELLANT[9]</td><td></td><td>✓</td></tr>
<tr><td>220 SEC. AFTER "BURN RCS PROPELLANT"</td><td>PURGE RCS PROPELLANT</td><td></td><td>✓</td></tr>
</table>

1. THE LEV IS NOT ABLE TO ACCELERATE AWAY FROM THE LV FOR LATER NEAR-PAD ABORTS, BUT FOR EARILER ABORTS THE LV MUST BE KEPT THRUSTING BECAUSE OF RANGE SAFETY.
2. FIRES FOR ABOUT 8 SECONDS, THOUGH AT DECAYING THRUST AFTER ABOUT 3.5 SECONDS.
3. FIRES FOR ABOUT 1.2 SECONDS.
4. LINE STRETCH IS APPROXIMATELY 0.8 SECONDS LATER, DISREEF 10 SECOND AFTER THAT AND FULL OPEN 0.2 SECONDS LATER.
5. INITATED WHEN THE ALTIMETER READING IS LESS THAN A ALIDADE MARKER. THE ACTUAL POSITION OF THE ALIDADE MARKER WILL BE SET ON THE DAY OF LAUNCH (REFERENCE 50) DEPENDING ON BAROMETRIC PRESSURE, BUT ACCORDING TO REFERENCE 1 IT WILL BE AT ABOUT 3,300 FEET.
6. INITIATED BY A BAROSWITCH.
7. MODE CHANGED BY A BAROSWITCH. FOR A NOMINAL ABORT THE MODE CHANGE OCCURS WHEN T_a = 38 SECONDS.
8. MAIN CHUTE LINE STRETCH IS APPROXIMATELY 2.0 SECONDS LATER, DISREEFS 6.0 AND 10.0 SECONDS AFTER THAT AND FULL OPEN 3.0 SECONDS AFTER SECOND DISREEF.
9. THIS BURN HAS CAUSED SOME CONCERN BECAUSE OF POSSIBLE DAMAGE TO THE MAIN CHUTES.



① THE VEHICLE IS LAUNCHED FROM PAD 34. THE 10 FOOT DEPTH LINE IS 1900 FEET FROM THE PAD IN A DIRECTION 20° NORTH OF EAST.

② FOR PAD ABORT WITH UPRANGE TIPOVER THE LEV TRAJECTORY HAS A RANGE WITH NO WINDS OF 2550 FEET AND A DIRECTION 8° SOUTH OF EAST (REFERENCES 6 AND 10).

③ THE RANGE OF A LEV TRAJECTORY IS REDUCED ABOUT 500 FEET BECAUSE OF 95TH PERCENTILE HEADWINDS (WINDS AROUND 50 FEET/SECOND) APPLIED TO THE LEV (REFERENCES 1 AND 20). TO BE CONSERVATIVE ASSUME THE RANGE IS REDUCED 300 FEET, WHICH RESULTS IN A CM LANDING POINT 90 FEET FROM THE 10 FOOT DEPTH LINE.

④ WINDS MUST BE APPLIED TO THE PARACHUTE DESCENT, WHICH TAKES ABOUT 100 SECONDS (FROM REFERENCE 11 FOR A TRAJECTORY WITH APOGEE GIVEN IN REFERENCE 10). IF THE 1 FOOT/SECOND ONSHORE WIND COMPONENT EXISTS FOR ALL ALTITUDES THE CM IS BLOWN 100 FEET TOWARD LAND.

FIGURE A1 - VERIFICATION OF THE REASONABLENESS OF A 1 FOOT/SECOND CONSTRAINT ON THE WIND COMPONENT FROM THE DIRECTION 72° EAST OF NORTH

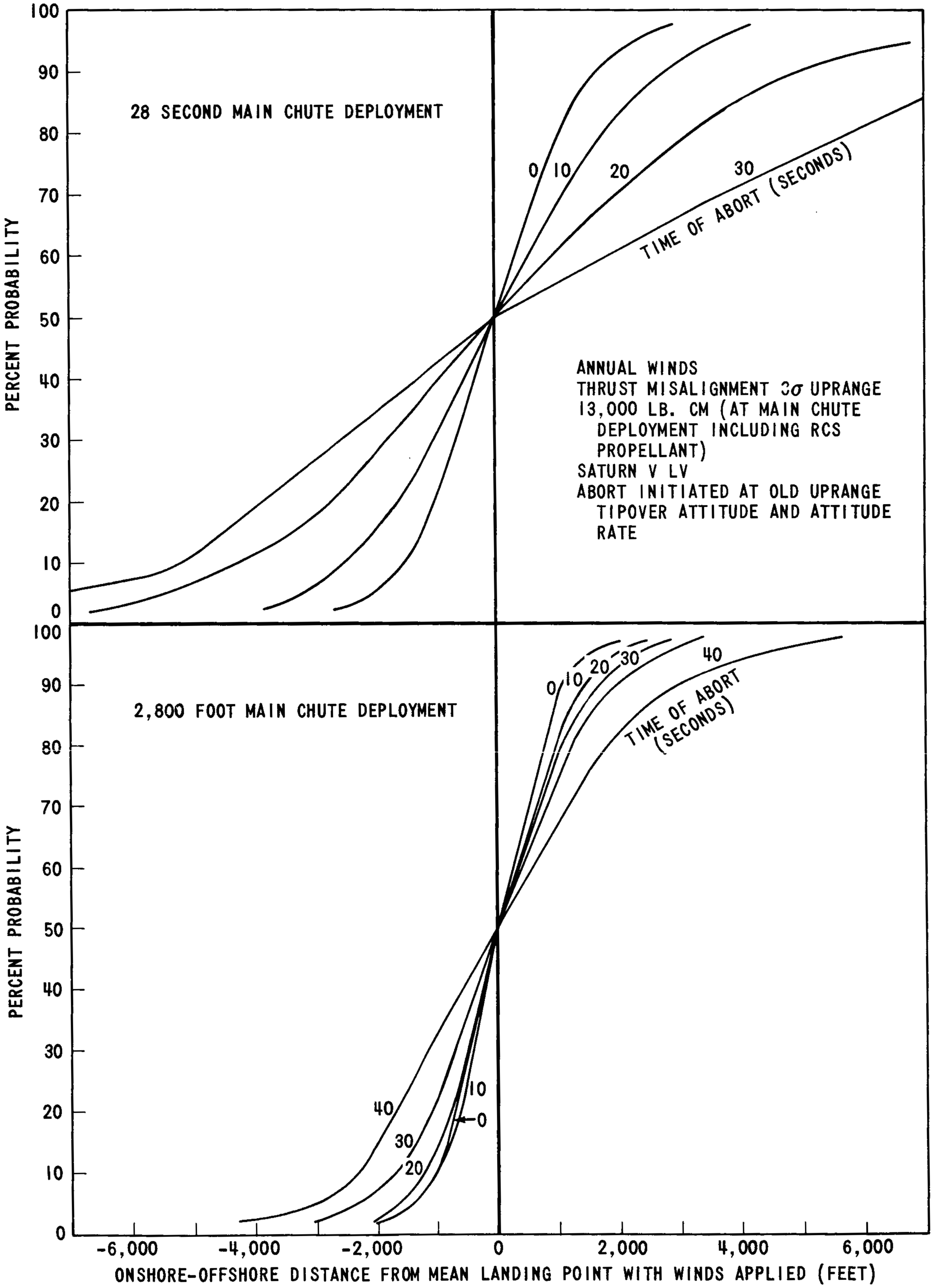


FIGURE A2 - DISTRIBUTION FUNCTIONS FOR WINDS APPLIED TO PARACHUTE DESCENT (REFERENCE 30)

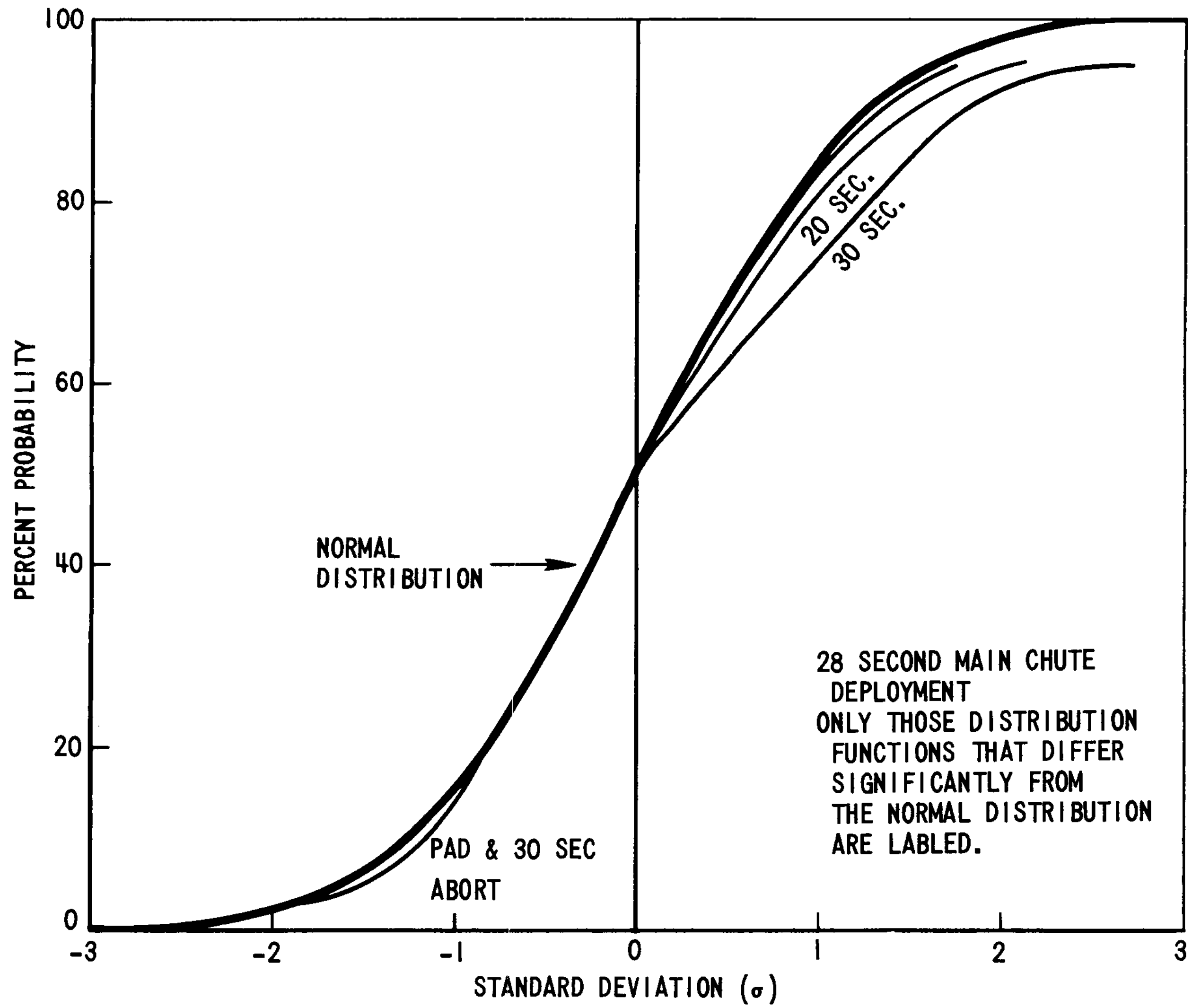


FIGURE A3 - COMPARISON OF A NORMAL DISTRIBUTION WITH EMPIRICAL DISTRIBUTION FUNCTIONS FOR CM LANDING POINT WITH WINDS APPLIED TO PARACHUTE DESCENT (FROM FIGURE A2)

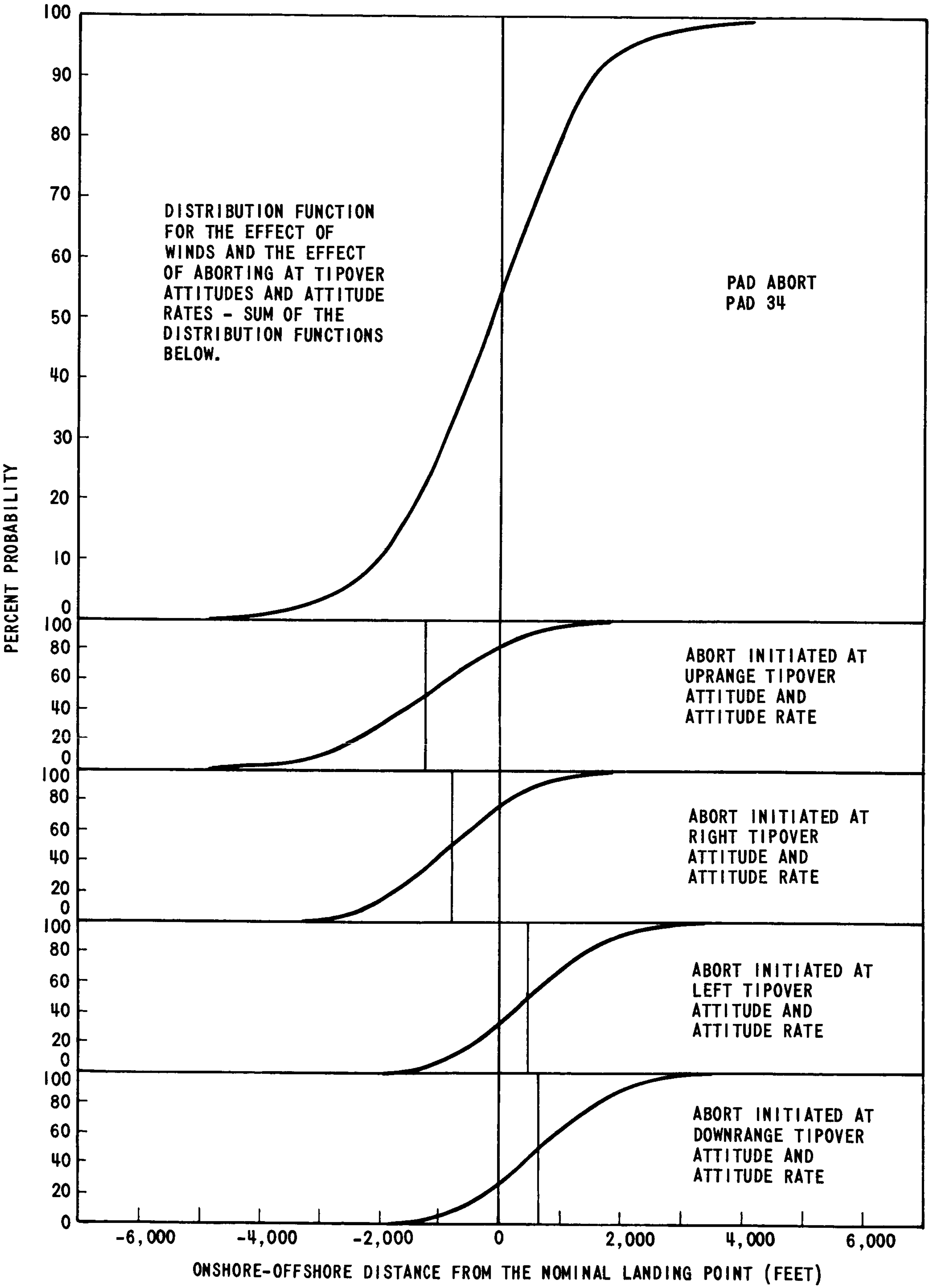


FIGURE A4 - ADDITION OF DISTRIBUTION FUNCTIONS FOR THE CM LANDING POINT

REFERENCES

1. DeFife, John E., Assistant Aerodynamics and Flight Dynamics Subsystem Manager, MSC, Conversation on August 14, 1968.

2. "Apollo Operations Handbook", Spacecraft Systems Operation Branch, Flight Crew Support Division, MSC, SM2A-03.

3. "Spacecraft Description, Block II Spacecraft", Volume I of Reference 2, SM2A-03–Block II-(1), March 1, 1967, latest change July 29, 1968.

4. "Apollo Mission Data Specification, Apollo Saturn 502", TRW Report No. SP-A-0003, Amendment No. 1, February 20, 1968.

5. "AS-205 First Stage Abort Probability Profile", Presented by MSFC to the Crew Safety Panel. Figure 6 of Reference 45.

6. "Summary of Malfunction Requiring Near-Pad Abort", From Boeing Document No. D5-15555-3A. Included in "Saturn V Launch Vehicle Emergency Detection System Analysis", MSFC Memorandum R-AERO-FF-45-68, April 22, 1968. Also Enclosure 14 of Reference 11.

7. Ives, Dallas G. and Samuel R. Newman, "Spacecraft Operational Abort Plan for Apollo 7 (Mission C), Volume I - LEV Aborts", MSC Internal Note No. 68-FM-224, September 12, 1968.

8. Ives, Dallas G. and Samuel R. Newman, "Apollo 6 (A-2 or AS-502/020) Operational Mode 1 Launch Escape Vehicle Abort Plan", MSC Internal Note No. 68-FM-76, March 21, 1968.

9. "Operational Abort Plan for the Apollo 8 Mission", Contingency Analysis Section, Flight Analysis Branch, MPAD, MSC Internal Note No. 68-FM-209, November 26, 1968.

10. "AS-205 Mission C (SA-205/CSM 101 Apollo 7) Emergency Detection System (EDS) and Flight Dynamics Limits", Flight Mechanics Panel and Flight Limits Sub-Panel, MSC and MSFC Joint Document 68-FMP-6, August 1, 1968.

11. "Final Documentation of the Twelfth Flight Limits Sub-Panel", meeting held on June 5, 1968, MSC Memorandum FM 13-440, August 5, 1968.

12. "Attitude and Attitude Rate Envelope for Saturn IB", MSC Memorandum 68-FM13-293, May 20, 1968. Enclosure 15 of Reference 11.

13. "Attitude and Rate Envelope for Saturn IB", MSFC Memorandom R-AERO-FF-60-68, May 27, 1968. Enclosure 16 of Reference 11.

14. "Final Documentation of the Thirteenth Flight Limits Sub-Panel", meeting held on August 19, 1968, MSFC Memorandum R-AERO-P-74-S-68, August 19, 1968.

15. Flight Limits Sub-Panel Action Item 12.3, Enclosure 3 of Reference 14.

16. "Near-Pad Abort Limits Based on LEV Performance", MSC Memorandum from Assistant Chief (Aaron Cohen), Systems Engineering Division, ASPO, PD4/M1126, May 28, 1968. Enclosure 5 of Reference 11.

17. "Report for Mission C, AS-205/CSM-101", Memorandum from Chairman (John D. Hodge), Apollo Crew Safety Review Board, to Apollo Program Director, June 14, 1968. Enclosure to Letter from Apollo Program Director (Sam C. Phillips, Lt. General, USAF) to KSC, MSC and MSFC, June 24, 1968.

18. "Status Report on Saturn V LEV Abort Capability", MSC Memorandum from the Assistant Aerodynamics and Flight Dynamics Subsystems Manager (John E. DeFife), ET255/6809-135, September 6, 1968. Enclosure 5 of Reference 14.

19. Mulheim, T. W., "Results of Studies/Analyses Related to Command Module Landing Test Programs", Response from APO-TIE to Apollo Action Assignment No. 546R. Boeing Document No. D2-11706B-1, May, 1968.

20. "AS-205 Abort Performance", Viewgraphs for a presentation gives by Bass Redd and John E. DeFife at the Design Certification Review (DCR) on the Flight Director and Recovery Support Prelaunch Computations at KSC on June 6, 1968.

21. Newman, Samuel R., Robert E. Prahl and Dallas G. Ives, "An Analysis of the Land Impact Problem during Mode I Aborts from the Saturn IB Launch Vehicle", MSC Internal Note No. 67-FM-167, November 6, 1967.

22. Henderson, Edward M., Alfred N. Lunde, and Samuel R. Newman, "Spacecraft Operational Abort and Alternate Mission Studies for AS-204A, Volume I, Abort Studies", MSC Internal Note No. 66-FM-113, October 28, 1966, Revision 1, December 21, 1966.

23. "Apollo Mission Data Specification D, Apollo Saturn 204A and 204B (U) (C)", TRW Report No. 2131-H00 4-R8-000.

24. "CSM/LM Spacecraft Operational Data Book", Systems Operations Branch, Systems Engineering Division, ASPO, MSC SNA-8-D-027.

25. "Mass Properties", Volume II of Reference 24, March, 1968. Amendment 12, "Mission 'C' LEV Mass Properties and L/D Tolerances", July 25, 1968.

26. Redd, Bass, "Evaluation of the Apollo Spacecraft Altimeter as a Primary Cue for Main Parachute Deployment During a Near-Pad Abort", MSC Memorandum, September 1, 1967.

27. Dietrick, Donald L., "The Effect of Wind Forces on a Thrusting Launch Vehicle and Launch Escape System for Apollo Mode I Aborts", MSC Internal No. 68-FM-22, January 25, 1968.

28. Smith, J. W., "Cape Canaveral Wind Summary Surface to 84 Kilometers", Terrestrical Environment Section, MSFC, MTP-AERO-62-3 (C-STAR Accession No. X63-80695), January 17, 1962.

29. DeFife, John E., Assistant Aerodynamics and Flight Dynamics Subsystems Manager, MSC, Conversation on August 21, 1968.

30. DeFife, John R. and Bass Redd, "Apollo LEV Abort Capability", Enclosure 8 of "Minutes of Engine-Out and EDS Analyses Meeting", held on August 10, 1967, MSFC Memorandum R-AERO-P-440-67, August 10, 1967.

31. Daniels, Glenn E., James R. Scoggins and Orvel E. Smith, "Terrestrial Environment (Climatic) Criteria Guidelines for Use in Space Vehicle Development, 1966 Revision", Aero-Astrodynamics Laboratory, MSFC, NASA TM X-53328, May 1, 1966.

32. Daniels, Glenn R., and Orvel E. Smith, "Scalar and Component Wind Correlations between Altitude Levels for Cape Kennedy, Florida, and Santa Monica, California", MSFC, NASA TN D-3815, April, 1968.

33. "Analysis of a Saturn V Pitch Program Modifications (S-Tilt), Proposed as an Aid to Reducing the Land Impact Probability after a Low Altitude Launch Escape Vehicle (LEV) Abort", MSC Memorandum from the Aerodynamics and Flight Dynamics Subsystem Manager (Bass Redd), ET225, 6712-91, December 13, 1967. Enclosure 8 of "Final Documentation of the Eleventh Flight Limits Sub-Panel", meeting held on December 20, 1967, MSFC Memorandum R-AERO-P-5-68, January 8, 1968.

34. DeFife, John E., Assistant Aerodynamic and Flight Dynamics Subsystem Manager, MSC, Telephone Conversation on July 30, 1968.

35. DeFife, John E., MSC Internal Note received by W. C. Brubaker from Bass Redd, July, 1968.

36. "Pad 24 Land Impact Probabilities for Various Main Parachute Deployment Sequences", MSC Memorandum from Aerodynamics and Flight Dynamics Subsystem Manager (Bass Redd) to the ASPO Manager, ET 225/6710-44, October 12, 1967.

37. "Mission AS-205 (Abort) Land Impact Studies, MSC Memorandum from the Aerodynamics and Flight Dynamics Subsystems Manager (Bass Redd) to the ASPO Manager, ET 255/6710-52, October 20, 1967.

38. "Saturn V 'Hold-Go' Probabilities Based on Land Impact After a Low Altitude Abort", MSC Memorandum from Aerodynamics and Flight Dynamics Subsystem Manager (Bass Redd) to Manager for Command and Service Module, ASPO, ET 255/6802-32, March 11, 1968.

39. "AS-205 Launch Restrictions Due to Land Impact After an Abort", MSC Memorandum from Aerodynamics and Flight Dynamics Subsystem Manager (Bass Redd) to Manager for Command and Service Module, ASPO, ET 255/6803-61, March 18, 1968.

40. "Design Certification Review Presentation", MSC Memorandum from the Mission Planning and Analysis Division Assistant Chief (Carl R. Huss), 68-FM36-256, May 29, 1968. Enclosure 6 of Reference 11.

41. "Prelaunch Real Time Mode I Abort Simulation Procedures for Predicting Land Impact for the AS-205/101 Mission", MSC Memorandum from the Mission Planning and Analysis Division Chief (John P. Mayer) to ASPO, 67-FM37-424, October 23, 1967.

42. Newman, Samuel R., Contingency Analysis Section, MSC, Conversation on August 14, 1968.

43. Ives, Dallas G. and Samuel R. Newman, "Prelaunch Measured Winds and a Comparison of the Effects of Prelaunch and Statistical Winds on Modi I Aborts from a Saturn IB Launch Vehicle", MSC Internal Note No. 68-FM-131, June 5, 1968.

44. Carter, E. A., and L. A. Schuknecht, "Analysis of the Atmospheric Environment During the Period 17 September to 16 October at Cape Kennedy, Florida, Related to Aerospace Vehicle Launch Criteria", Work performed for the

Terrestrial Environment Branch, MSFC, under Contrast NAS8-20082, Lockheed Missiles and Space Company/Huntsville Research and Engineering Center, A791753, TM 54/50-111, August, 1968.

45. "Spacecraft 101 Near-Pad Aborts", MSC Memorandum from Assistant Chief (Aaron Cohen), Systems Engineering Division, ASPO, PD5/M271-17.1, October 20, 1967.

46. "Mass Properties Data Book", Volume III of Reference 14, Revision I, November, 1968.

47. "Pad/Near Pad Abort, Mode IA, Simulation Results", MSC Memorandum from Chief (Warren J. North), Flight Crew Support Division to Assistant Chief (Aaron Cohen), Systems Engineering Division, ASPO, CF 243-7M-77, October 20, 1967.

48. DeFife, John E., Assistant Aerodynamics and Flight Dynamics Subsystems Manager, MSC, Telephone Conversation on September 10, 1968.

49. DeFife, John E., "AS-503 LEV Aborts, Comparison of Standard and Steerable Abort Systems", Drawing obtained by J. D. Richey, April 4, 1968.

50. "CSM Data Book", Volume I of Reference 24, prepared by North American Rockwell Corporation, May 1, 1968.

51. "Operational Procedures", Volume II of Reference 2, SM2A-03-SC 101-(2), March 1, 1967, latest change May 1, 1968.

52. "Additional Wind Statistics for Apollo Spacecraft Abort Studies", MSFC Memorandum from the Terrestrial Environment Branch (S. Clark Brown and Orvel E. Smith) to the Flight Limits Sub-Panel Chairman, R-AERO-YT-90-67, July 25, 1967.

53. "Approximate Winds for Land Impact Probability Prediction for AS-205", MSC Memorandum from Aerodynamics and Flight Dynamics Subsystem Manager (Bass Redd), Enclosure 18 of Reference 11.

54. DeFife, John E., "Apollo LEV Abort Capability", MSC Memorandum, May 24, 1967.

55. Smith, Orvel E., "Copy of Vu-Graphs", For presentation to the AS-205 Mission Rules Meeting held at KSC on September 5, 1968, Terrestrial Environment Branch, MSFC, September 4, 1968.

56. Canfield, Normal L., Orvel E. Smith and William W. Vaughan "Progress in Circumventing Limitations of Upper Wind Records", Journal of Applied Meteorology, Vol. 5, p. 301, June, 1966. Enclosure 7 of Reference 11.

57. Canfield, Normal L., Orvel E. Smith and William W. Vaughn, "Serial Completion of Upper Wind Records", Journal of Geophysical Research, Vol.72, No. 4, p. 1389, February 15, 1967.